A METHOD TO DETECT CHANGES IN JOINT ANGLES BEFORE AND AFTER A SPEED CHANGE

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Introduction

When transitioning from one constant walking speed to another, the lower limb kinematics are expected to change [1]. This change likely manifests as a shift in the mean value of the joint angle and/or a change in the range of motion (ROM). To model the transition itself, a method to continuously capture the changing joint kinematics is needed [2]. One potential option is detrending [3], wherein the joint angles are decomposed into an approximately constant, periodic signal multiplied by a trend. In preparation for analysing the speed transition itself, this work evaluates if detrending can detect a difference between the approximately steady-state regions before and after a speed change.

Methods

21 healthy subjects walked on a treadmill while joint kinematics were recorded [4]. Every 17 steps, the treadmill changed between 5 normalized speeds (0.40, 0.43, 0.46, 0.50, 0.53) in a random order. Subjects were notified of the new speed 3 steps before the change occurred. Subjects performed each possible speed transition 10 times. The joint angles were split into steps, and resampled at 500 points per step. To analyze each transition, data from 9 steps before the speed change to the step before the next notification step (24 steps total) were used.

Preliminary analysis as well as visual inspection indicated that the joint angle's mean and ROM changed during the transition. The joint angle $\theta = T \cdot P$ was decomposed into a time-varying trend T, and an approximately constant periodic P signal (Fig. 1). The trend was estimated by taking a moving average with a symmetric window sized to 2 steps. Thus, the trend primarily captures changes in the mean angle.

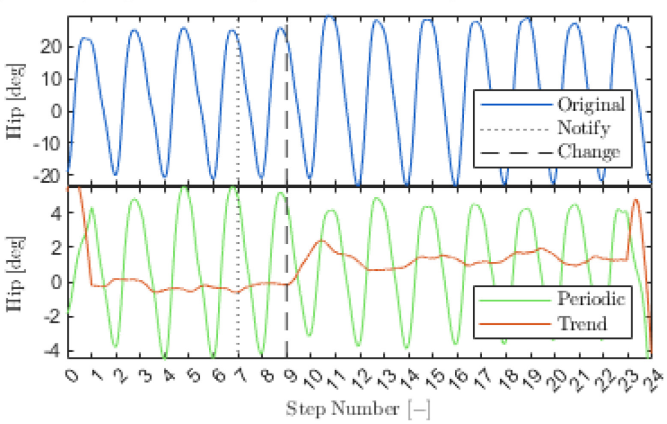

Figure 1: Original signal (top) and trend and periodic components (bottom) for +4 speed change. The trend shows a clear change over the transition, while the periodic component does not.

To determine if the trend was statistically different before vs. after the change in belt speed, the trend from steps 2-5 and steps 14-17 were compared using a Mann-Whitney U Test with α=0.05. This was done for each transition and joint. The percent of trials with statistically significant differences for each transition size (±1, ±2, ±3, ±4) and joint (hip, knee, ankle) was computed.

Results and Discussion

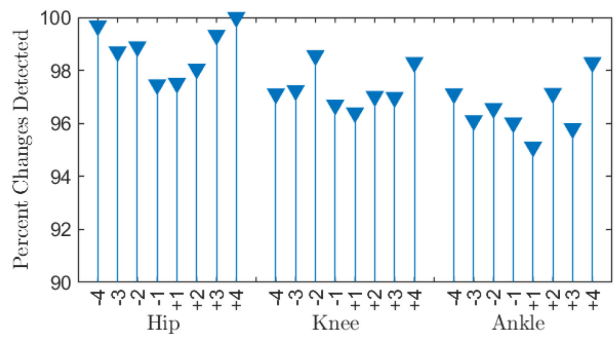

Figure 2: Percent of transitions with changes in joint angles detected. For all transition sizes and joints, over 90% of transitions had statistically significant changes in the trend.

This method detected changes in joint angles for the vast majority of transitions (Fig. 2), indicating that the mean joint angle changes with walking speed as expected. While the complete change in the joint trajectories includes a time-varying amplitude as well, the basic detrending method used here appears to be sensitive enough to capture key kinematic changes. The smallest detection percentage for all joints and transition magnitudes was that of the ankle at a +1 speed change (95%).

In general, the hip exhibited larger, more easily detectable changes than the knee and ankle, as indicated by the average percent of changes detected (99% for hip, 97% for knee, 96% for ankle). In addition, the transition magnitude affected the hip differently than the knee and ankle. For the hip, the percentage of detected changes increased as the transition magnitude increased. The knee and ankle do not exhibit this same pattern. Thus, detrending is also sensitive enough to detect joint-specific behaviors. This will inform future work to develop a model capable of capturing the transition itself.

Significance

The presented method of detecting changes in joint kinematics for speed transitions will inform further investigation into when the transition begins and ends. The transition region can then be accurately modelled. Such a model could allow for more natural speed changes in exoskeleton and prosthesis controllers. Additionally, such a model could be used to quantify and compare how different populations change speeds.

Acknowledgments

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References

[1] Oberg and Karsznia, 1994, J. Rehabil. Res. & Dev., 31 (3): 199-213.
[2] Embry et al, 2018, IEEE Trans. Neural Syst. Rehabil. Eng., 26 (12): 2342-2350.
[3] Bennet, 1979, Spatial Time Series, Pion Limited.
[4] Rodman and Martin, 2020, J. Biomech., 112: 110068