Do Switched Linear Dynamical Systems Provide Robust Kinematic Predictions of Healthy Treadmill Gait at Different Speeds?

Taniel Winner
Biomedical Engineering, Emory University and Georgia Institute of Technology,
Atlanta, USA
twinner3@gatech.edu

Trisha M Kesar
Rehabilitation Medicine, Division of Physical Therapy,
Emory University,
Atlanta, USA
tkesar@emory.edu

Lena Ting
Biomedical Engineering, Emory University and Georgia Institute of Technology,
Atlanta, USA
lting@emory.edu

***Abstract*— Data-driven models can potentially be used to segment gait data into phases as well as to predict gait kinematics. Previous research [1] used switched linear dynamical systems (SLDS) to model individual-specific representations of kinematic data from healthy individuals walking on a treadmill. Here we show that SLDS representations trained at one speed can identify gait phase from data obtained at a different gait speed. However, prediction of future kinematics over timescales of up to 1 second, require individual- and speed- specific models.**

Keywords-Switched Linear Dynamical Systems, Gait Speed

I. Introduction

Machine learning methods can classify different gait patterns, demonstrating that they encode different dynamics. Recently, data-driven SLDS models have been used to predict the transitions between single and double support gait phases. SLDS models can also predict joint kinematics over relatively long time horizons. However, we do not know whether these models generalize across walking speeds. Here we tested the ability of SLDS models trained on an individual's kinematic data at a single speed to effectively reconstruct kinematic data of different gait speeds.

II. Methods

Two healthy individuals (1 males/1 female, 28±1 year) were enrolled in this pilot study. Participants walked on a treadmill at a comfortable self-selected speed, and at a fast speed. Kinematic data was collected at 100 Hz using a 7-camera Vicon system and forces collected at 2000 Hz using an instrumented dual-belt treadmill. We used SLDS to model the bilateral lower limb joint angle trajectories during gait. An SLDS is a set of linear dynamical systems with discrete modes that govern when to switch between the individual linear models using Hidden Markovian model approach. Specifically, we used an autoregressive SLDS, which can be written as in (1).

$$\boldsymbol{x_{k+1} = A_{z_k} x_k + w_k(z_k)} \qquad \textbf{(1)}$$

Where $z_k \in \{1, \ldots, N\}$ is the discrete mode, x_k is the state vector at time step k, A_{z_k} is the linear system parameters and $w_z(z_k)$ is a zero-mean, Gaussian noise term [2]. We trained an SLDS with four discrete modes on 9 trials of each participant's gait data at one speed and tested the model's ability to predict gait phases and kinematics at different speeds.

III. Results and Discussion

Training and testing SLDS models (n=6) on datasets of the same gait speed of 0.9 mps resulted in an average phase prediction (aPPA) of 92.76% ± 0.70 % and average root mean square error (aRMSE) over all joint angle reconstructions of 3.26˚ ± 0.57˚ (range: 1.22 ˚ -7.96 ˚). When testing these models on 1.3 mps speed data (n = 9), the aPPA decreased by 0.17% and aRMSE increased by 166.87% (range: 4.36˚ – 17.79˚). Training and testing SLDS models (n=6) on the same gait speed of 1.3 mps resulted in aPPA of 96.85% ± 0.80% and aRMSE 2.90˚ ± 0.40˚ (range: 1.24˚ -6.55˚). When testing these models on 0.9 mps speed data (n = 9) the aPPA decreased by 4.7% and the aRMSE increased by 161% (range: 3.80˚-16.49˚). Although SLDS results in high phase segmentation accuracy, Fig. 1 shows that it does not have great kinematic prediction a gait speed different gait than the one it was trained on.

Fig. 1. Left ankle reconstructions using different SLDS models tested on 1.3 mps data.

IV. Conclusion

Despite the ability of SLDS to model with high gait phase prediction accuracy (>92%) across different speeds, kinematic predictions do not appear to be generalizable across different speeds for the same individual. Future studies will evaluate methods to improve generalization of these models across speeds and walking conditions.

Acknowledgment

This work is supported by the National Science Foundation GRFP to Taniel Winner and M3X CMMI1762211. SLDS code was developed and written by Luke Drnach.

References

[1] Drnach, Luke, et al. "Identifying Gait Phases from Joint Kinematics during Walking with Switched Linear Dynamical Systems." BioRxiv, 2018, doi:10.1101/378380

[2] Chiang, J., et al. "A Hidden Markov, Multivariate Autoregressive (HMM-mAR) Network Framework for Analysis of Surface EMG (sEMG) Data." IEEE Transactions on Signal Processing, 2008. 56(8): p. 4069-4081.