"Drift and deadbeat control in the Floquet structure of human running"
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Motivation

Understanding the dynamical structure of running gaits finds application in clinical biomechanics, sports medicine, prosthetics and robotics. Gaits have been modelled with everything from simplified "templates" to meticulously detailed musceloskeletal models. Much of this work presumes stability of a limit cycle for the dynamics, and seeks to identify how this stability is brought about through control laws. We report recent results from our work shedding light on some of the dynamical structure, present evidence that this structure is compatible with the theoretical predictions of Carver, Cowan & Guckenheimer (2009), and discuss extensions to previous methods that made our analysis possible.

State of the Art

Variations of the spring-loaded inverted pendulum (SLIP) model of running have been in use since their introduction in early 1980's. Work in recent years has focused on a variety of control protocols that stabilise SLIP gaits in models and robots. Biomechanical studies examined the strategies animals (e.g. humans, guinea fowl) use to recover from perturbations in running.
We have proposed a complementary approach to the prevalent one of fitting of low-dimensional SLIP dynamics to COM data derived from running kinematics : the use of Data Driven Floquet Analysis. Based on Floquet's theory from the 1880's, we know that all smooth stable limit cycle oscillators can be reduced by change of coordinates to a time invariant linear system on $S^1 \times D^{(n-1)}$. The presence of a "template" in the dynamics and some of its structural properties can be recovered from the data with the methods we pioneered.

Discussion Outline

In his thesis and related publications, Carver proposed an argument that a 3D SLIP model cannot achieve deadbeat control in less than two step. Further, Carver, et. al. proposed some deadbeat control strategies that possess left-right symmetry. The presence of such a controller is expected to have a signature in the matrices recovered by Data Driven Floquet Analysis.

We subjected several long (1800 stride) datasets of treadmill running from multiple individuals, collected by Maus, to Floquet Analysis. The analysis produced evidence for non-stationarity and long-range correlations, layered on top of a deadbeat controller. The phase dependence of prediction quality suggests that this controller shares structural features with those expected based on Carver's theoretical predictions.

The discussion will include additional methodological issues regarding the application of Detrended Fluctuation Analysis, and a detailed comparison of Floquet multiplier estimation using naïve methods versus multiple-section methods similar to those proposed by Wang and Srinivasan in the 2011 ASB meeting.

Format: 15 minute talk

Keywords: Floquet analysis; running; deadbeat control