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Characterizing and Modeling the Joint-level Variability in Human Walking

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Abstract

Although human gait is often assumed to be periodic, significant variability exists. This variability appears to provide different information than the underlying periodic signal, particularly about fall risk. Most studies on variability have either used step-to-step metrics such as stride duration or point-wise standard deviations, neither of which explicitly capture the joint-level variability as a function of time. This work demonstrates that a second-order Fourier series for stance joints and a first-order Fourier series for swing joints can accurately capture the variability in joint angles as a function of time on a per-step basis for overground walking at the self-selected speed. It further demonstrates that a total of seven normal distributions, four linear relationships, and twelve continuity constraints can be used to describe how the Fourier series vary between steps. The ability of the proposed method to create curves that match human joint-level variability was evaluated both qualitatively and quantitatively using randomly generated curves.

Keywords: Variability, Human Gait, Modeling

1. Introduction

A major motivation for investigating gait variability is quantifying fall risk. Mean temporal measures have consistently failed to differentiate between fallers and non-fallers (Hamacher et al., 2011; Hausdorff, 2007). In contrast, measures of gait variability can successfully identify individuals at risk for falls (Hamacher et al., 2011; Hausdorff, 2007) and with fear of falling (Sawa et al., 2014). In general, increased variability indicates increased fall risk and is often assumed to be correlated with decreased stability (Hamacher et al., 2011). For some physiological systems, a moderate amount of variability is indicative of a healthy, flexible system, and this may be true for gait (Hausdorff, 2007; Stergiou and Decker, 2011). Further, variability and stability may not be equivalent (Dingwell et al., 2001). Regardless of the exact connection between variability and stability, measures of variability likely provide different information than mean values.

Variability has traditionally been viewed as purely random fluctuations about a desired mean (e.g., (Pailhous and Bonnard, 1992)), and thus, the structure of the variation is assumed to be uninteresting. Variability has typically been quantified using standard deviations (or equivalent, e.g., (Danion et al., 2003; McGinley et al., 2009; Winter, 1984)), which provides no information about how variability at one instant affects variability at a later instant, either for the current or subsequent steps. Similarly, stochastic statistical

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