Modeling Human Walking with HZD-Based Control and Impulsive Toe-Off

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1 Motivation

Due to experimental difficulties, almost no scientific evidence to date definitively indicates that one lower-limb prosthesis performs better than another [3]. A model of walking that is simple enough to allow systematic exploration of prosthesis design variables, yet detailed enough to accurately capture step dynamics, could help fill this gap. Unfortunately, such a model does not yet exist, even when the problem is simplified to a healthy subject.

2 State of the Art

Human gait models range from highly dimensioned to very simplistic. Highly dimensioned models either mimic recorded human motion [6] or are too complex to easily use in iterative design [7]. Very simplistic models can provide information about a single part of gait, but not the whole gait [5]. Simple models controlled using hybrid zero dynamics (HZD) techniques [8] offer a promising compromise. Because they lack toe-off [2], though, current HZD-based models do not efficiently redirect their center of mass velocity like humans do [1]. As a result, HZD-based model gaits differ from human gaits to compensate for the lost energy. This research demonstrates that such simple models can be modified to have human-like energy transfer at impact.

3 Approach

The symmetric, planar four-link model consists of a point mass at the hip (mass of the HAT), two massive thighs, and two massive shanks with attached circular feet [4] (Fig. 1). A step consists of a finite-time single support phase controlled using an HZD-based controller and an instantaneous impact to switch the stance leg. During impact, an additional impulse is applied at the hip to capture the effects of toe-off. Model gaits based on human walking data were created over a range of speeds using an optimization to match average experimental speed, step length, and joint kinematics. For comparison, gaits with no toe-off were found using the same objective function.

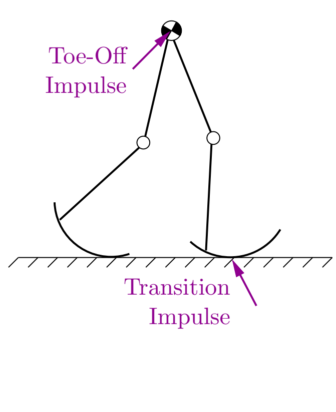

Figure 1: Schematic of the model at impact. The arrow at the hip indicates the toe-off impulse and the arrow at the foot indicates the transition impulse.

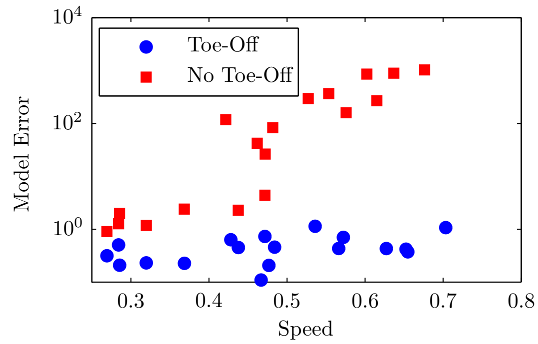

Figure 2: Normalized and combined model error in speed, step length and joint kinematics vs. normalized speed for simulations with and without toe-off.

4 Results

Incorporating toe-off into the model significantly improves the matching of human data, particularly at faster speeds (Fig. 2). Without toe-off, the simulated speed matches the experimental speed closely but with a shorter step length and an average joint error of 11°. With toe-off, the simulation matches both the experimental speed and step length exactly, with an average joint error of 4° for all speeds.

5 Best Possible Outcome

These results demonstrate that an HZD-based four-link model with an impulsive toe-off can accurately model human gait. Using this model, an objective function that can be used to predict human gait over a range of speeds and toe-off conditions will be developed, making it possible to quantify the performance trade-offs involved in designing prostheses with differing toe-off characteristics.

References

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