AN ANALYTICALLY TRACTABLE MODEL FOR A COMPLETE GAIT CYCLE

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INTRODUCTION

Human walking is complex due to a human's many degrees of freedom (DOF) and the periodic impacts that occur at leg exchange. This has resulted in models of walking that either deal with only limited aspects of the gait, for example, models of only the swing phase, or models that attempt to be all-inclusive that include, for example, all of a human's DOF and musculature [1]. As a result, these models have limited use for clinical judgments, which are usually based upon gait analysis heuristics or statistical comparisons. The work described here deals with the development of an analytically tractable hybrid model to model an entire gait cycle of human walking (a forward-dynamic model). The model is validated using experimental data for normal gait reported by Winter [2].

This analytical model, in turn, will lead to a low-dimensional model that captures the essential dynamics of human walking. Such a *template* dynamical model is considered possible because of the observed parsimony of human gait (Figure 1). Having such a model has important implications for clinical applications and could lead to the development of analytical tools that, for example, predict the effect of anthropometric changes, or enable analysis of systematic changes to prosthetic alignment instead of relying on heuristics.

METHODS

Since the gross motions during human walking take place in the sagittal plane, a 2D model is developed. (Extension of the model to three dimensions is planned.) The hybrid dynamic model consists of three parts, the single support phase, a leg-ground contact event, and a double support phase. The analysis of the continuous phases (single and double support) is developed using standard robotics analysis: Kinematics are obtained via the Denavit-Hartenberg convention and then Lagrange's method is used to derive the equations of motion [3]. The discrete phase, (leg-ground contact event) is modeled as a rigid impact. We term this approach "robomimetic" in that the inspiration for this approach is from a framework developed for the systematic design and analysis of controllers to induce stable walking in planar biped robots [4].

The single support phase model is of five rigid links: two shanks, two thighs and a HAT segment. The weight-bearing leg has a rocker foot, the shape of which is determined using the roll-over shape model of Hansen [5]. The single support model is valid from heel contact to opposite heel contact.

A rigid impact model, which acts instantaneously, is used to model the transition from single support to double support. The model captures the energy loss associated with this event.

The model for double support (DS) is of six rigid links, with the trailing limb's ankle joint being actuated. This additional DOF is to enable the model to capture the impulse at toe-off.

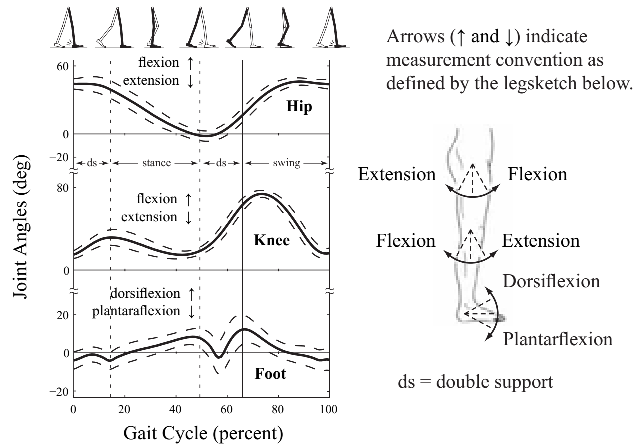

Figure 1: Average joint angles for five subjects using five trials each. Note strikingly small variation in the joint trajectories, which indicates that humans use their DOF parsimoniously, and with uniformity, while walking. Data courtesy of J. Linskell, Limb Fitting Centre, Dundee, Scotland.

To validate the model, the energies of the segments are computed using the hybrid model and compared with the data for a single normal gait cycle reported by Winter [2].

RESULTS AND DISCUSSION

The analytical model described is a first step in the development of a low-dimension model of human gait. Preliminary comparisons of the data generated from this analytical model show that the model is able to capture well the energetics in the single support phase. Note that, in a first analysis, the DS model's trailing limb ankle was not actuated. This model was not able to accurately capture the energetics of the DS phase. With the addition of an actuated ankle, the energy burst that appears at toe-off is captured.

The parsimony of human gait and the successful use of an analytically tractable low-dimension model to implement stable walking in a biped robot [4] suggest that a template dynamical system for human walking is possible. The model developed here provides the foundation for this approach.

REFERENCES

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