Advancement of Legged Locomotion Models by Including Nonlinear Damping

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Accurately predicting human locomotion has been a goal of various mathematical models. Early canonical models of locomotion were developed to predict the basic features of ground reaction forces (GRF). More recently, modified hip actuated and leg damped locomotion models have been developed to better predict the stability and robustness of human and animal locomotion. Such improvements have resulted in the loss of the characteristic GRF predicted by earlier models. Historically, GRF are among the most common measures to experimentally study human locomotion. Thus, it is important to develop new mathematical models that predict both accurate stability of motion, as well as GRF. We hypothesized that by replacing linear damping models with nonlinear leg damping, we can better replicate human GRF. We then derived the equations of motion for this new type of locomotion model and analyzed the system behavior. GRF from the modified model were compared with published human GRF data. Stability and robustness were also studied through the use of numerical analysis to make sure that the ability to predict stable motion was not compromised. We found that the modified model with nonlinear leg damping provides a significantly better prediction of GRF, especially in the early part of stance. Further, the model's ability to predict the stability of locomotion is similar to the actuated model with linear damping. As a result, we expect that stable actuated models of locomotion can generally be combined with nonlinear leg damping models to better predict human locomotion GRF and stability.