A passive spring-mass model with rolling contact and leg masses to investigate the ballistics of swing dynamics

W.G. Charles, *R.S. Ransing, I. Sazonov and M.I. Friswell

College of Engineering, Swansea University, Swansea SA1 8EN, UK

*r.s.ransing@swansea.ac.uk

Summary

The compliant spring model for periodic walking has been shown to emulate Ground Reaction Forces (GRFs), however these models have massless limbs and and therefore do not simulate the swing phase dynamics. The simple mass-spring model is updated to include a mass at each limb to simulate the ballistic nature of the swing phase. We investigate the effects of spring stiffness, roller radius and mass ratios on the GRFs, spatio-temporal characteristics and the stability of gait. We also compare results with gait experiments to see how well this model matches human data. This research can be used to understand the biomechanics of walking to help design better walking devices and robots.

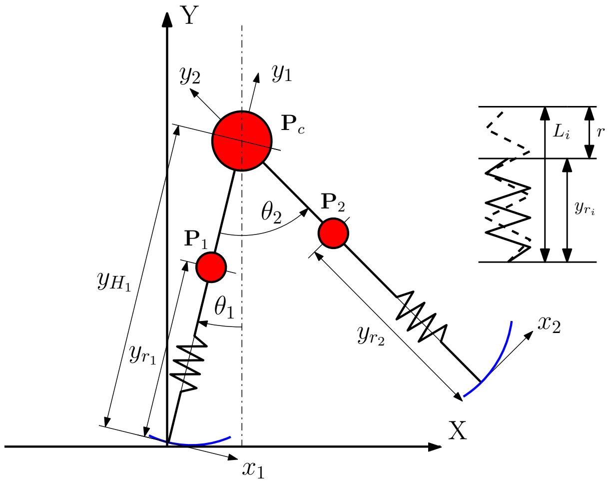

Figure 1: Passive walking model with springs

Introduction

A passive dynamic walker has been used as a simple model to investigate and understand biomechanics since McGeer (1990), however the rigid inverted pendulum model is unable to appropriately match the 'double-hump' GRF curve seen in human walking. Geyer et al. (2006) showed that a spring-mass walking model can produce the nature of the GRF curve, and investigated its relation to effective leg stiffness and touch-down angle. Whittington and Thelen (2009) improved this model by adding a roller to the foot to better match the spatio-temporal gait characteristics. This also predicted speed-dependent changes is GRFs and centre of pressure excursions.

However, these passive spring-mass models only have a hip-mass, so do not have swing leg dynamics. Usually, the 'angle of attack' determines the angle of foot placement. The authors have created a model to include the swing leg dynamics.

Model set-up

Lagrangian mechanics are used to derive an uncontrolled, unpowered walker. The model has a hip mass and a smaller mass at each leg as seen in Figure 1. The foot contact is a rocker of radius 1/3 of the leg length to better match human data and increase efficiency (Adamczyk et al., 2006). There is a partially inelastic collision at heel strike, so to regain the energy lost at the collision, the model walks down a slight incline. During single support stance phase, there are 4 degrees of freedom, $\theta_1, \theta_2, r_1, r_2$, which can be reduced to just θ_1 and r_1 during the double-support phase.

Results

Effects of leg mass ratios, foot geometry and slope angle can give good insight into passive mechanical properties of the swing leg dynamics of the spring-mass model. We can look at the effects of these parameters on walking speed, GRFs and similarities to the human system. The Basin of Attraction can also give insight into the stability of the walker with different parameters such as mass ratios, foot contact and spring stiffness.

Further to this model, it be can seen if adding a damper (Etenzi and Monaco, 2015) will increase the stability of the walker and achieve steeper slopes and greater walking speeds. Also, Song et al. (2016) has shown that a springy pendulum can match swing leg kinetics. This will be added to the current model to see if it better matches swinging leg kinematics.

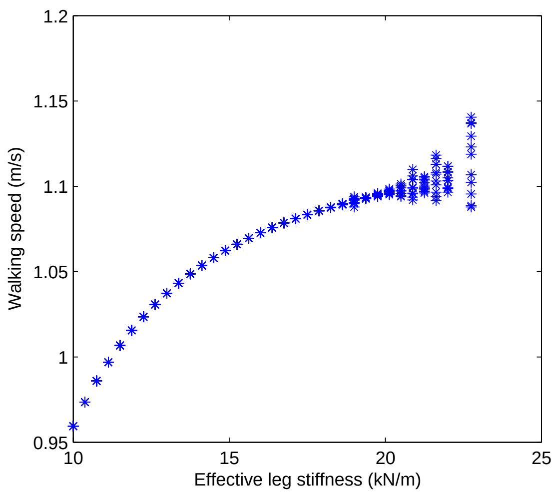

Figure 2: Using physiological masses and foot shape, walking down a slope of 3° and damping coefficient, b = 500 Ns/m.

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