1. Title:

Virtually underground pivoted compliant bipedal model explains COP excursion during human walking

2. Motivation:

A compliant inverted pendulum model with a lumped mass is proposed to explain basic characteristics of human gait dynamics in both walking and running [1]. However, due to a point contact foot in the model, center of pressure excursion (COP) is restricted at a point unlike the heel-to-toe COP excursion observed in human. Moreover most of previous bipedal walking models calculate the step length based on a kinematic constraint from a predetermined heel strike angle [1,3], without consideration of the kinetic constraint by the COP. Therefore, an alternative gait model that incorporates with the dynamics and constraint on COP excursion is required to better represent human gait dynamics.

3. State of the Art:

Drawing an analogy between cyclic COP progression over foot and a roller, few passive walking robots[2] and mathematical walking models utilized rocker-bottom feet[3] to reproduce the progression of COP. In normal gait cycle, it is observed that the COP location relative to ankle position follows a circular shape.[4] However, this roller foot analogy is only confined to normal walking and thus cannot serve as a general explanation for COP excursion in various ground contact conditions, such as walking on an even terrain.

4. Own approach to this question:

From the experimental data of ground reaction force(GRF) of human walking, we observed that the COP excursion within a foot seemed to result in COM rotation about a virtual pivot point located underground. Therefore, to incorporate with the dynamics and constraint on COP excursion during a gait cycle, we proposed a compliant legged bipedal model with underground pivot point (UPP). The model consists of a point mass and massless spring pivoted to a point derived geometrically by heel strike angle and foot length. As COM rotates about UPP, the COP location, the intersection of spring and the foot, advances forward to represent COP excursion Moreover, as in human walking, the UPP model makes the heel strike when COP of trailing leg reaches its location of metatarsal (approximately 3/4 of foot length) [4]. This is different from other models that the phase shift criterion only decides when to make heel strike, and therefore the heel strike angle and step length are decided by kinematic constraints of given instant. We performed parameter study to examine the feasibility and the robustness of the proposed gait model and its resemblance to human gait characteristics

5. Discussion outline: key questions and potential solutions:

The UPP model simulation showed COP excursion and GRF direction change trend similar to experimental observations. In addition, the model showed a great robustness to initial condition and self-stabilization as in human. We show that setting the pivot below the ground significantly reduces COM rotation range and induces more vertically oriented force than the previous ground point contact models. From the stability study, we reveal that these changes in rotation range and direction of GRF in fact help the system to remain within the more stable parametric region. Further, we show that self-selection of step length and heel strike angle for different velocity can be explained by the model. Finally, we question that humans might modulate UPP to control gait dynamics.

6. Format: Talk

7. Keywords: COP excursion, Compliant leg, Underground pivot point

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