

**Introduction**

Two most representative strategies for human characters to keep standing are the postural balance strategy and the reactive stepping strategy. In both strategies, the stepping motion is created from the planned trajectories of CoM and/or the swing foot. In many cases, the desired trajectories are generated to form smooth geometric curves, without considering the character’s dynamics. For that reason, it is typically difficult to find suitable control parameters to follow the desired trajectories (e.g., wobbling behavior of a PD controller). If an additional perturbation is applied during the reactive stepping, the desired trajectories may need to be updated, which requires non-trivial efforts to switch to the new trajectories.

We suggest the trajectory-free reactive stepping strategy for physics-based characters using momentum control. Our controller is characterized by moving passively in the direction of external pushes without attempting to follow some prescribed trajectory, thereby achieving a natural reactive stepping behavior adaptive to various perturbations.

**Related Work**

Postural Balance Strategy

The postural balance strategy is usually chosen for relatively short and mild perturbations, against which a character can maintain balance in place simply by controlling the ankle or hip joints, or by rotating the whole upper body. Macchietto et al. [2] proposed a whole body postural balance controller that identifies the desired CoP as the high level input.

Reactive Stepping Strategy

Upon the long or strong perturbations, a character should take a reactive stepping strategy in which a character takes one or more steps to prevent falling. Recently, researchers have applied momentum control approaches to reactive stepping. Wu and Zordan [3] introduced a momentum control approach which generates parameterized curves for the swing foot and center of mass (CoM) trajectories according to the step position and duration. The method subsequently creates whole body motions to realize the trajectories via joint accelerations optimally calculated from the multi-objective function and joint torques computed by inverse dynamics.

**Momentum Controller**

Given the desired momentum rate change, one can compute the joint torques to realize the momentum rate change as closely as possible.

\[
\dot{\mathbf{p}} = \mathbf{C}_u \mathbf{a} + \mathbf{f} + \mathbf{T}_n,
\]

\[
\mathbf{T}_n = \mathbf{C}_n \mathbf{a} - \Gamma \mathbf{k}.
\]

In the absence of external force, the linear and angular momenta of a system are conserved. Also, the total external moments and external forces, respectively, are equivalent to the rates of change of linear and angular momenta. Applied to a standing character, if no external perturbations are present, momentum change comes only from the ground reaction forces (GRF) and gravitational force.

\[
k = (g - r_G) \times f + \tau_n
\]

\[
l = mg + f
\]

**Framework**

Postural balance strategy and reactive stepping strategy.

**Results**

**Interactive Game Play with Balancing Character**

We implemented an interactive game framework that integrates the gesture-based user interface using both the Kinect and a smartphone into the physics-based virtual environment. A user can directly push or pull a physics-based character and can shoot a bullet by tapping a button on the phone.

**References**


