Footstep Navigation for Dynamic Crowds

Shawn Singh Mubbasir Kapadia Glenn Reinman Petros Faloutsos

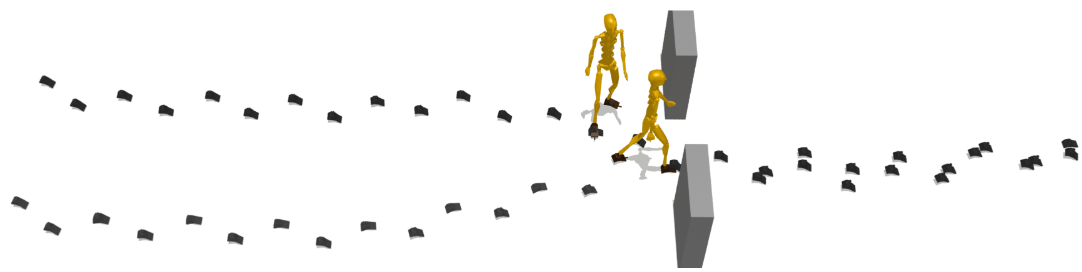

Figure 1: Footsteps generated for two characters navigating through a doorway. The top-left character side-steps to let the other character proceed first. Footstep navigation allows characters to maneuver with spatial precision, temporal precision, and natural steps.

1 Introduction

The majority of previous crowd ‘steering algorithms model each character as an oriented particle that moves by choosing a force or velocity vector. In many cases, orientation is heuristically chosen to be the same as the particle’s velocity. This approach has the two key disadvantages:

- *Limited locomotion constraints:* Vector commands do not account for constraints of real human movement. Trajectories may have discontinuous velocities, oscillations, awkward orientations, or may try to move a character unnaturally, and these side-effects make it harder to animate the character intelligently. or example, a character moving forward cannot easily step to the right when its left foot is in the air (swing phase).
- *Limited navigation control:* It is common to assume that an animation system will automatically know how to interpret a vector-based steering decision. However a vector does not have enough information to indicate appropriate subtle maneuvers, such as side-stepping versus reorienting the torso, stepping backwards versus turning around, stopping and starting, planting a foot to change momentum quickly, or carefully placing footsteps in exact locations. These details are critical to depicting a character’s local steering intelligence, and thus it is appropriate for steering to have better control.

We propose a steering algorithm that generates sequences of footsteps instead of a vector command. There are already several animation techniques that can animate a character to follow timed footsteps exactly so the focus of our work is how to *generate* footsteps for crowds of characters. Prior work on generating footsteps focuses on individual characters in static environments; details about choosing proper foot orientations, step timing, and collision avoidance with footsteps have received little attention in prior work.

2 Our Method

We represent a character’s center of mass trajectory using a parabola for each step (Figure 2a). The footstep is located with respect to the origin of this parabola. Each step is described by the exit velocity $(\dot{x}, \dot{y})$, timing, and curvature of the parabola. These three degrees of freedom allow a large variety of steps, including normal straight walking, curved walking, stopping, stopping, side-stepping, back-stepping, and foot plants for sharp turning. To navigate characters, we use a planner to find a near-optimal energy-efficient sequence of steps that avoids collisions and satisfies constraints while navigating towards a goal.

Our method ensures biomechanically valid footsteps. First, steps that cause excessive stride lengths and steps that are too fast or two slow are considered invalid and will not be considered by the planner. Second, an interval of valid foot orientations is also maintained for every step, constrained by the previous step and the chosen trajectory. If this interval becomes over-constrained by a certain step, that footstep is considered invalid. The exact foot orientation can be properly chosen by a fast post-process. Third, we model the cost of taking each step. Energy dissipates with every step (Figure 2b), and therefore the total cost of a sequence of steps is minimized by maintaining momentum and avoiding unnecessary turns.

Results. Our method produces natural, collision-free, human-like navigation for crowds of characters in real-time, yet it also exhibits more *local* intelligence than existing vector-based steering algorithms. Characters do not get stuck and “fight” around doorways. Instead, one of the characters side-steps predictively or adapts his trajectory with a subtle speed change to avoid contending with other characters at the doorway. Our characters can step carefully to avoid holes in the floor, while simultaneously navigating to avoid collisions with other characters to reach a goal. Users can intuitively tweak constraints such as step length, width, timing, character height, etc., to create unique walking styles – for example, even an asymmetric limping gait. The density of characters packing in a crowd is not limited by a coarse collision radius; our characters can place their feet close to others without collisions, much like real humans in crowds. Finally, even with the additional precision, control, and intelligence of footsteps, our method can still navigate hundreds of characters in real-time.

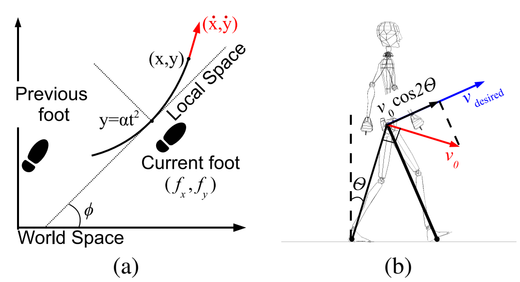

Figure 2: (a) Parabolic approximation of a single step. (b) Momentum decreases from v_0 to $v_0 \cos(2\theta)$ due to heel-strike.

I3D 2011, San Francisco, CA, February 18 – 20, 2011.
ISBN 978-1-4503-0565-5/11/0002