Real-Time Character Stepping for Computer Games

Ben Kenwright

Abstract—Generating life-like virtual characters that portray an illusion of realism produces more immersive, engaging, and addictive virtual worlds; for example, in training simulations and computer games. However, creating virtual human characters that can adapt to unforeseen circumstances, such as trips and pushes, in a realistic, physically-correct, and life-like manner in real-time is challenging, interesting, and important. The challenges stem from the fact that synthesizing a human's full-body movements in a natural manner is complex due to the intricate anatomical structure and stylistic deviations of humans (i.e., the large number of degrees-of-freedom (DOF) and diverse range of behavioral characteristics). One fundamental movement that is crucial for balance and life-like exploration of virtual worlds is stepping. Whereby, the character supports itself and remains upright and balanced during standing and walking by means of its feet and legs. For push disturbances the character can automatically counteract the disturbance by means of placing the feet at specific locations on the ground. This paper explains how intelligent physics-based techniques in conjunction with various simple controller mechanisms can create autonomous self-driven character stepping animations that are robust and reactive. We demonstrate how to avoid the common foot sliding artifacts and physically-implausible poses (e.g., unbalanced and hovering above the ground).

Index Terms—procedural, intelligent, physics-based, goal-driven, animation, characters, key-framed, beyond, inverted pendulum, balancing, autonomous, intelligent, biped

1 Introduction

Human avatars are a common site in interactive virtual worlds, such as video-games and training simulations. However, creating physically accurate, controllable, adaptable, and interactive biped character animations on-the-fly and in real-time that mimic real-world humans is challenging, interesting, and important. This is because humans possess a huge number of degrees of freedom and are capable of producing a vast assortment of diverse, original, and complex movements that are both physically bound (i.e., balanced and dynamic) and life-like.

These are very exciting times for computer graphics animation. A number of diverse and original techniques are becoming plausible and practical with computers increasing in speed. For example, virtual humans solutions are mixing robotics based methods with biomechanically inspired techniques to produce more life-like physically correct and interactive characters that break the mold. The days of hard-coded, inflexible, data-driven solutions are making way for procedural self-driven smart solutions.

1.1 Low-Dimension View

We make the problem as simple as possible (i.e, a low-dimensional model), since this provides the following advantages:

- The balancing motion can be decoupled from the overall motion
- We can focus specifically on one crucial stepping motions
- The full-body movement can be reconstructed around the simple model (we can take advantage of the redundancy as a secondary priority means of mixing in behavioral emotions, such as tired and happy)

• *Ben Kenwright*
E-mail: bkenwright@xbdev.net

1.2 Stepping

Focusing on an important and crucial area of animation (i.e., the stepping motion) we can go a long way to creating more life-like and plausible character animation solutions. Furthermore, these techniques can be combined with other systems (e.g., motion capture data) to generate full body motions.

However, there are two important questions that this paper attempts to answer: (1) In what situations do we need stepping and how can we mimic the real-world without motion capture data? (2) How can procedural stepping simulations combine control with dynamics (i.e., stylistic control while obeying the laws of mechanics)? We will completely answer both questions in this paper. Firstly, we simplify the problem, in that we prove that for every multi-body character system there is a dynamical and kinematic equivalent point-mass equivalent representation. Hence, our results and models focus on a point-mass system that can be applied to a character multi-body simulations.

Will procedural techniques replace hand created animations? Remember the old "hand-drawn" cartoon animations? Animations could go the same way! Instead of artists manually creating and editing existing key-framed movements, they could be created automatically based on intelligent physics-based algorithms (e.g., [1], [3]).

2 Equivalent Multi-Body Systems Point-Mass Construct

We show here that every multi-body system has an equivalent dynamic and kinematic equivalent point-mass representation. We base the explanation on the energy of conservation of a multi-body systems, which consists of interconnected rigid-body links with uncomplicated joints,

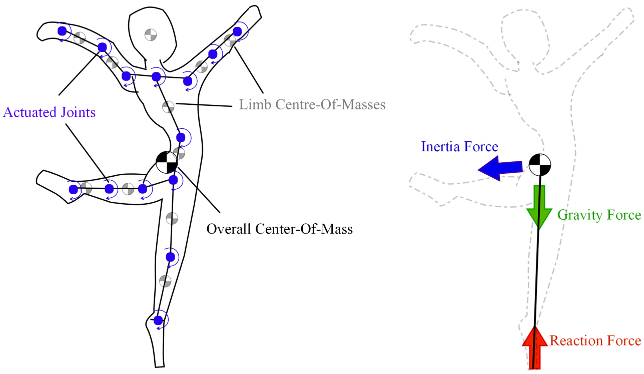

Fig. 1. **Simplifying the Articulated Character Model** - Reducing the complexity of the complex human body multi-body system down to a point-mass and contact point.

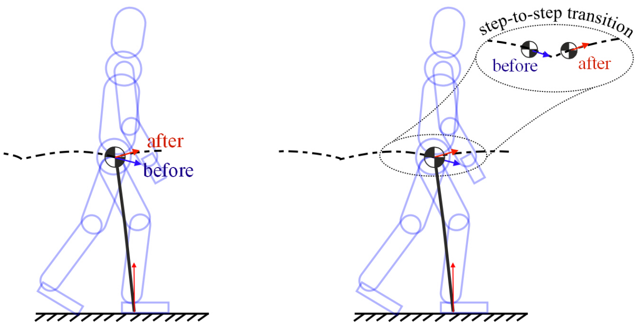

Fig. 2. **Pendulum-Stepping Model** - A point mass and a single contact point can be used to represent the 'fundamental' stepping motion of a human.

such as revolute connections (e.g., hinge-joint, ball-joints, and spherical-joints).

The principle is that the multi-body system can be decomposed into its individual rigid body elements. Each rigid body element has its own point-mass equivalent that we can combine to represent a single overall system point-mass. Furthermore, we sum up the inertia tensors for the system of interconnected bodies to form a total unified inertia tensor representation.

Approximating a complex multi-body system as a point-mass significantly reduces the complexity of the problem, permitting both faster and more accurate simulation of fundamental motions. For practical investigations with respect to stepping motions this enables us to focus on specific areas of animation without worrying processing and enforcing the multitude of constraints.

3 Single Support Point Pendulum Stepping Model

As shown in Figure 2, we can simplify biped balanced stepping movements down to a single support point and a particle mass. The principle is based on you pivoting your body around your foot (i.e, the one that is on the ground), as if you were using that leg to "pole-vault" your centre-of-mass (somewhere around your pelvis-belly) in an arc like motion (e.g., see Figure 2). As you plant your foot on the ground in front of you, the ground exerts a force back up your leg that slows you down, and you continue slowing as you rise up on your support foot to the top of your arc. At that point, your kinetic energy is at a minimum, while your potential energy is at its maximum. Then, as you fall forward into the next step, the stored potential energy is converted back into kinetic energy, and you accelerate again.

How can we mimic a human's walk? One approach, is biomechanically inspired inverted pendulum. It has been shown that a human walking motion behaves similar to that of an inverted pendulum. The pendulum model works by transforming kinetic energy into potential energy, and back, in equalizing ratios, during stepping transitions. In a perfect world, the pendulum stepping motion would convert the kinetic to potential energy perfectly (i.e., 100 percent). However, in reality, humans are only about 60 to 70 percent efficient. Therefore, we burn calories while walking, since our muscles create heat due to resistances.

4 Mapping: Bridging the Gap between Control and Kinematics (IP to Full-Body)

We address the issue of mapping the low-dimensional model onto a fully articulated biped skeleton. There are a number of unknowns that must be addressed, such as foot and arm trajectories. The inverse kinematic (IK) solver maps a solution between our IP model and our highly articulated biped skeleton hierarchy. While the highly articulated skeleton contains a huge amount of flexibility and ambiguity (i.e., multiple solutions for achieving the same goal), in comparison to the simplified low-dimensional model which is minimalistic, computationally efficient, and straightforward to solve. The simplified model, however, possesses multiple attributes (i.e., overall center-of-mass position and feet locations) that are common to the highly articulated skeleton, which are fundamental for generating physically correct balanced biped stepping poses. To accomplish the mapping efficiently, we subdivided the IK problem into two separate parts (i.e., upper and lower body). This made solving the IK problem faster and more robust. Moreover, our adaptive stepping technique solves balancing logic while the upper-body motions are left free for alternative actions, such as personality and style (e.g., looking around, arms' swaying).

We focused on lower body movements since they are the most crucial for upright balancing motions [4] compared to the upper body. While, foot trajectories were generated by interpolated Bezier splines between the current and desired landing positions during foot transitions.

The final motions did not use any motion capture or key-framed libraries. Hence, some of the motions may have appeared to look a bit robotic. This approach can be remedied by combining the generated motions with a multiple priority IK solution (i.e., with a primary and secondary goal) [2]. Whereby, the primary balanced physically correction motion are always enforced, while the secondary less crucial aesthetically pleasing life-like motions are combined on top from sources, such as key-framed libraries or random motion generators

5 Summary

We are going to see film and game animations take on a new form. Similar, to how we saw computer generated graphics replace traditional hand drawn scenes, we will see procedural physics-based solutions replace traditional pre-recorded key-framed motion capture solutions. Exploiting techniques

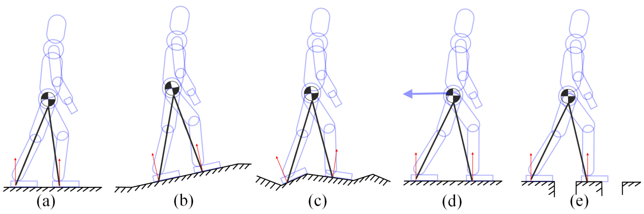

Fig. 3. **Pendulum-Stepping Requirements** - We can adapt the pendulum based model to account for various situations. (a) flat terrain, (b) slopes, (c) uneven ground, (d) pulling/pushing forces, (e) stepping stones (i.e., avoiding holes).

from multiple research disciplines (such as biomechanics, robotics, and computer science) to create intelligent self driven characters.

Reducing the complexity of the problem to its fundamentals (i.e., point-pass and contact points for the body and feet) we can generate physically-plausible human-like stepping motions that are responsive and dynamic. This makes the game characters more dynamic, enhances immersion and widen the audience for interactive entertainment.

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