Human Motion Synthesis Using Contact-Invariant Optimization

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1 Introduction

We present an automatic technique for synthesizing human-like locomotion, including walking, running, gait initiation, gait termination, jumping, and kicking. The technique does not rely on hand-designed task-specific control architectures or motion capture data. Our method is based on spacetime optimization of a 3D humanoid character, actuated by a small set of musculotendon units. A single metabolic effort objective is used for all synthesized motions. Contact forces are discovered together with the motion trajectory. The synthesized walking and running motions exhibit kinematic, torque, and muscle activation patterns that are quantitatively similar to human data.

2 State of the Art and Proposed Solution

One natural approach to human motion synthesis is to design controllers for humanoid characters in physics-based forward simulations. Of particular relevance to our work is [2], which demonstrated how human-like straight steady-state walking and running motions can emerge from modeling musculotendon properties and effort minimization given a control structure specifically designed for locomotion.

An alternative we pursue is a single trajectory optimization formulation that does not rely on motion data or task-specific priors. In particular, we use contact-invariant optimization (CIO) [1]. This optimization framework smoothes out discontinuities in the objective and allows a single continuous optimization to search over the space of possible motion trajectories and contact patterns.

While CIO has been previously used on reduced character models, we apply the framework to full humanoid characters with equations of motion that express the detailed dynamics of the body. In order to enable fine-grained optimization over contact timings, we simplify and generalize the CIO formulation by eliminating the quantization of contact patterns that previous formulations relied on. This allows the optimization to tune the timing of the motion and increase its fidelity.

To further increase the realism of the synthesized motion, we incorporate simple musculotendon models in the lower extremities. This regularizes the synthesized torque patterns and enables the incorporation of a biologically-plausible effort model. Unlike prior work that utilized musculotendon models and metabolic energy expenditure objectives to produce human locomotion [2], we do not assume a task-specific control structure. As a result, we are not limited to steady-state walking and running.

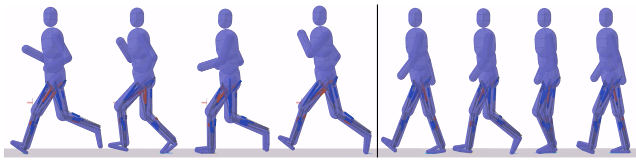

Figure 1: Locomotion results generated by our method

3 Current Results

We synthesize locomotion limit cycles by specifying task terms that capture the goal of moving the model's trunk forward with a target speed and a target upright head orientation as well as cycle duration. Locomotion results at speeds from 0.5m/s walking to 5.0m/s running can be generated. Shift in strategy from walking to running is made automatically as target speed increases. Non-cyclic motions, such as gait initiation and termination, as well as jumping and kicking are also synthesized.

Supplementary plots and video may be viewed at:
www.cs.washington.edu/homes/mordatch/dw2013.pdf
www.cs.washington.edu/homes/mordatch/dw2013.mov.

References

[1] Mordatch, I., Todorov, E., and Popović, Z., "Discovery of complex behaviors through contact-invariant optimization," ACM Trans. Graph. 31, 2012.

[2] Wang, J., Hamner, S., Delp, S., and Koltun, V., "Optimizing Locomotion Controllers Using Biologically-Based Actuators and Objectives," ACM Trans. Graph. 31, 2012.