Physics based Simulation for Locomotion of Biped Characters

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Biped Character Locomotion

Image source: [Phase 2 report](#)
Problem

- **Character controller**
  - Generate motion that are result of physics-based simulation process
  - Interaction between the characters
  - Animation of fictional and imaginary biped characters
Related Work

- SIMBICON (Simple Biped Locomotion Control)
- Generalized Biped Walking Control
- Optimizing Locomotion Controllers Using Biologically-Based Actuators and Objectives
- Flexible Muscle-Based Locomotion for Bipedal Creatures
Motion Generator

- Design a Finite State Machine
- Condition for transition between states
- Torques computed by Proportional Derivative (PD) Control

\[ \tau = K_p (\theta_d - \theta) + K_d \dot{\theta} \]
Motion Generator (contd)

- Use **motion trajectories** derived from **Motion Captured Data**
- Modeled as phase of a step $\phi \in (0,1)$ using catmull rom splines
- Now PD control changes to

$$\tau = K_p (\theta_d - \theta) + K_d (\dot{\theta} - \dot{\theta}_d)$$

source: SIMBICON
Torso and Swing hip control

- Torques for stance hip is computed to achieve desired net torque at the torso(pelvis)

\[ \tau_{\text{torso}} = -\tau_{\text{swing hip}} - \tau_{\text{stance hip}} \]
Foot Placement Strategy

- **Balance FeedBack**
  - Add feedback term of the form

\[ \theta_d = \theta_{d0} + c_d \ d + c_v \ v \]
Foot Placement Strategy (contd)

- **Inverted Pendulum Model**
  - Computes desired stepping point \((x_d, z_d)\)
  - Equate total mechanical energy at present state with that at the balanced rest state
    \[
    \frac{1}{2}mv^2 + mgh = \frac{1}{2}mv'^2 + mgh'
    \]
    where \(v' = 0\) and \(h' = L = \sqrt{h^2 + d^2}\)
  - In sagittal plane \(x_d = d\) and \(z_d\) is equated in coronal plane
  - Height of the swing foot is defined as a phase \(y(\phi)\)

Image source: [Generalized Biped Walking Control](#)
Velocity Tuning

- Virtual force to control the centre of mass velocity
- Similar to manipulating ZMP in order to balance the character
- The torque to realize the virtual force is calculated as

\[ \tau_V = J_V^T F_V \]

Image source: Generalized Biped Walking Control
Gravity Compensation

- Allows for low-gain PD control
- Apply a virtual force $F_i = m_i g$ to COM of each link $i$
- The torque to realize this virtual force

$$\tau_i = J_i^T F_i$$

Image source: Generalized Biped Walking Control
Results

- Manual Controller
• A Controller imitating MOCAP data
• A controller using IPM model and Compensation torques
Conclusion

- Obtained natural gait for manual and motion capture controller
- Transition between motion styles are not always smooth
- Collision between the legs should can be avoided
- More sophisticated control system can layer on top of these controllers
References

- Thomas Geijtenbeek, Michiel van de Panne, and A. Frank van der Stappen. Flexible muscle-based locomotion for bipedal creatures. ACM Transactions on Graphics, 32(6), 2013
Related Work (contd)

- **SIMBICON**
  - A finite state machine
  - Torso and swing-hip control
  - Balance feedback for swing foot placement
Evaluating value from Catmull Rom Spline

- Find where $t$ lies
- Now interpolate

$$p(t) = (2t^3 - 3t^2 + 1)p_0 + (t^3 - 2t^2 + t)m_0 + (-2t^3 + 3t^2)p_1 + (t^3 - t^2)m_1$$

● Generalized Biped Walking Control
  ○ Motion generator
  ○ Inverted pendulum model for swing foot placement
  ○ Velocity tuning and Gravity compensation torques

Image source: Generalized Biped Walking Control, ACM, 2010
Related Work (contd)

- **Optimizing Locomotion Controllers Using Biologically-Based Actuators and Objectives**
  - Uses *musculotendon units* to generate torques
  - Biologically-motivated control functions
  - The parameters of these functions are optimized to prevent the character from stumbling down
Related Work (contd)

- **Flexible Muscle-Based Locomotion for Bipedal Creatures**
  - Uses 3D muscle models to drive the motions of the body
  - Introduces muscle routing optimization
  - Uses *muscle-based Jacobian Transpose* Approximation
Thank You