CSE 888.14 Advanced Computer Animation
Final Presentation

Topic: Locomotion

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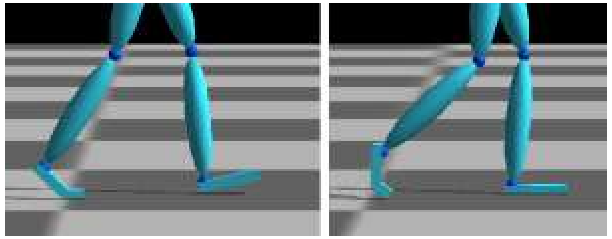
Locomotion

- **How a character moves from place to place.**
- **Optimizing walking controllers.**
  J. M. Wang, D.J. Fleet, and A. Hertzmann, University of Toronto, *Siggraph Asia 2009.*

Optimizing walking controllers (*Siggraph Asia 2009*)

- Describes a method for optimizing the parameters of a physics-based controller for full-body, 3D walking.
- Observed how to choose critical parameters for tuning to achieve better walking control and reasonable walking style
- Resulting gaits exhibit key properties of natural walking, for example, energy efficiency.
  - *toe-off, heel-strike*



- The system does not require any motion capture data.

Optimizing walking controllers (*Siggraph Asia 2009*)

- Optimizing a controller involves
  - searching for control parameters
  - a start state that together produce good character simulations.
- Objective Function
  - weighted sum of several terms
  - features of human walking
  - constraints: User gait, Required gait, Head and body,
  - Efficiency and power terms
- A modified version of the SIMBICON controller is optimized.

Character Model and Controllers

- Character Model:
- 30 internal degrees-of-freedom (DOFs)
- toe blocks, which are connected to the feet by hinge joints
  - provide more flexibility during landing and ankle toe-off
- Single-state controller:
- Torque for each joint DOF (drive each joint to its desired local angle)

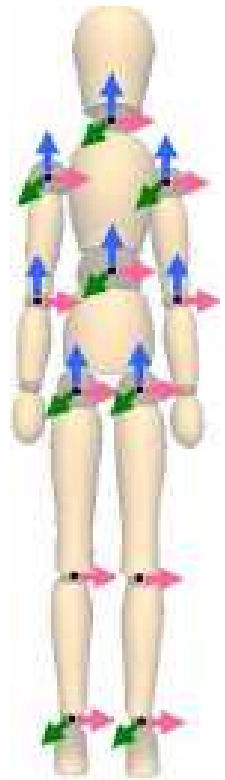
$$\tau = k_p\left(\theta_d - \theta\right) + k_d\dot{\theta},$$

gain and damping coefficients (k_p, k_d)

target angle (θ_d)

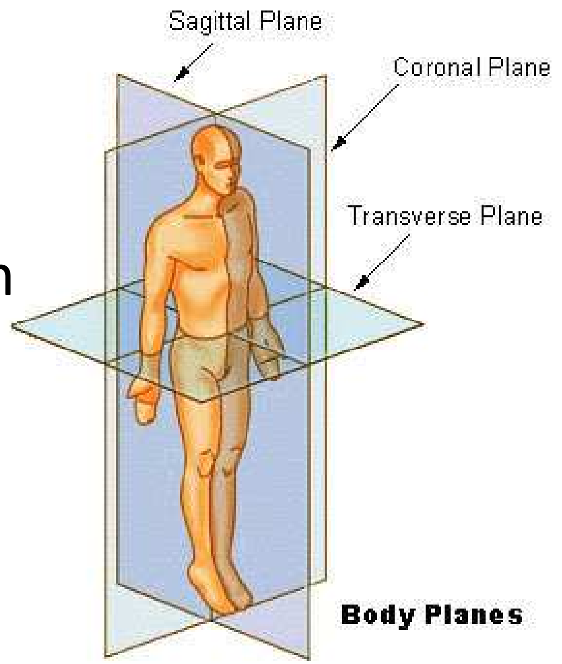
current joint angle (θ)

angular velocity ($\dot{\theta}$)



Character Model and Controllers

- Single-state controller:
- target angle of the arm DOF (in the sagittal plane) , allows the model to synchronize arm swing with the legs



$$\theta_{larm} = \alpha_{arm}(\theta_{rhip} - \theta_{lhip}) \ , \ \ \theta_{rarm} = -\theta_{larm}$$

↑ scale factor.

Character Model and Controllers

- State machine and transitions

State #	0	1		2	3	
Left Foot	Swing	Swing	Contact	Stance	Heel-off	
Right Foot	Stance	Heel-off		Swing	Swing	Contact

- The transition to state 1: when the signed horizontal distance (in the sagittal plane) between the center-of-mass (COM) of the body and the ankle of the stance foot exceeds a threshold
  - motivated by our observations of when stance ankle push-off appears to occur
  - differs from SIMBICON which uses a time-based transition.

Character Model and Controllers

- State machine and transitions

State #	0	1	2	3
Left Foot	Swing	Swing Contact	Stance	Heel-off
Right Foot	Stance	Heel-off	Swing	Swing Contact

- During state 1, the swing leg prepares for landing, and the stance ankle push-off begins.
- Transition to state 2 occurs when the swing foot makes contact with the ground.
- States 2 and 3 are left/right reflected versions of states 0 and 1, with mirrored parameters.

Character Model and Controllers

- Start state:
  - manually initialized to when the left leg is in the middle of its swing phase, prior to the transition from state 0 to state 1.

Start State		
DOF	q_0	$\dot{q}_0$
$globpos_x$	free	1.3
$lhip_y$	-0.4	0.3
$lknee_y$	1.35	0.1
$lankle_y$	0.35	-15
$rhip_y$	-0.4	1.0
$rknee_y$	0.6	2.0
$rankle_y$	-0.2	-9

Controller				
State	0		1	
DOF	k_p	θ_d	k_p	θ_d
$back_{xyz}$	300	0	300	0
$rhip_y$	1000	-1	1000	-0.65
$lknee_y$	300	-1.3	50	-0.55
$lankle_x$	30	0	50	0
$lankle_y$	300	3	300	-0.35
$rknee_y$	150	0.4	500	-0.5
$rankle_y$	300	-0.2	300	0.75
$ltoe_y$	20	0	20	0
$rtoe_y$	20	0	20	0.6

- Fix DOFs and other parameters that are unlikely to contribute to the task:
  - joint DOFs that rotate with respect to the local x and z axis are fixed to zero, back joint is an exception (for trunk rotation in the gait).

Controller Optimization

- Objective function:
  - evaluates simulations of duration 10 seconds (T simulation time-steps).
  - a weighted combination of terms motivated by task constraints and biomechanical features of human walking.
- thresholded quadratic

$$Q(d;\epsilon) = \begin{cases} d^2, & \text{if } |d| > \epsilon \\ 0, & \text{otherwise} \end{cases}$$

Controller Optimization

- User gait constraints

$$E_{user} = Q(v_x - \hat{v}_x; \epsilon_{vel}) + Q(s - \hat{s}; \epsilon_{step})$$

average forward speed (v_x) or step length (s)   user-specified targets

- Required gait constraints
  - Encourages Vy and Vz to be small, and the start velocity V0x to be similar to the average x velocity of the simulated motion. (optimize for walking in the positive x).

$$E_{vel} = Q(v_y; \epsilon_{vel}) + \lambda_{vel} \left[Q(v_{0x} - v_x; \epsilon_{vel}) + Q(v_z; 2\epsilon_{vel}) \right]$$

  - encourages left-right symmetric timing of the controller. (requires left and right strides to have approximately the same duration.)

$$E_{sym} = Q(\Delta t_0 - \Delta t_2; \epsilon_t) + Q(\Delta t_1 - \Delta t_3; \epsilon_t)$$

Controller Optimization

- Head and body constraints
  - prevent unnatural arm swing, where the arms and legs are badly out of phase.

$$avgL = \frac{1}{T}\sum_{t=1}^{T} \dot{L}_t^2,$$

$\dot{L}_t$ is the derivative of the normalized angular momentum about the COM in the vertical direction

$$E_{ang} = Q(\sqrt{avgL}; \sqrt{\epsilon_{ang}}),$$

  - stabilize the head motion: the lateral and vertical motions of the head are typically smooth with small amplitudes (helps to stabilize the visual and vestibular systems)

$$E_{head} = Q(\sqrt{\sigma_{head}}; \sqrt{\epsilon_{head}}) + \frac{\lambda_{head}}{T}\sum_{t=1}^{T} orient_t,$$

Controller Optimization

- Efficiency and power terms
  - human walking is powered more by the ankle than the hip

- Complete objective

Complete objective. The complete objective function for walking is given by

$$E = \sum_s w_s E_s, \quad (16)$$

where $s \in \{user, vel, land, fail, sym, ang, head, power, ratio\}$. We use the following parameters for all experiments: $w_{user} = 100$, $w_{vel} = 100$, $w_{land} = 1.2$, $w_{fail} = 120000$, $w_{sym} = 100$, $w_{ang} = 10$, $w_{head} = 100$, $w_{power} = 10^{-5}(70/mass)$, $w_{ratio} = 1$, $\lambda_{vel} = 0.01$, $\lambda_{head} = 0.012$, $\epsilon_{vel} = 0.025$ m/s, $\epsilon_{step} = 0.025$ m, $\epsilon_t = 0.025$ s, $\epsilon_{ang} = 0.05$ /s^2, $\epsilon_{head} = 0.1$ m/s.

- http://www.youtube.com/watch?v=DYWohqHQ23A

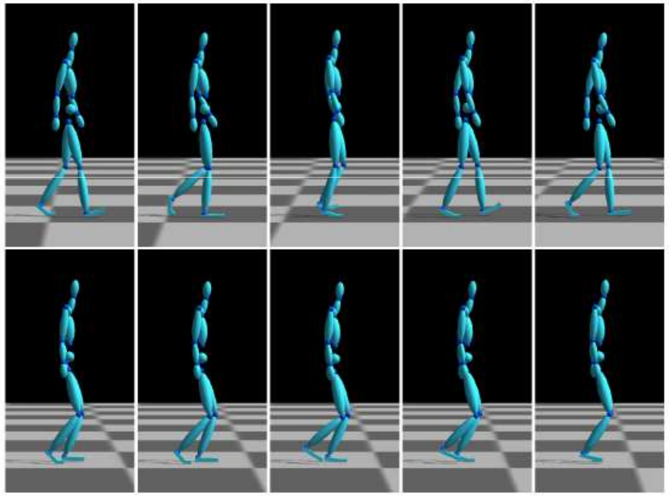


Figure 3: ***Top:*** *Optimization of "short" (Figure 8(bottom)) walking in 1.0 m/s.* ***Bottom:*** *Optimization without E_{ratio}. The lack of the power ratio term leads to a semi-crouching style.*

Optimizing walking controllers (*Siggraph Asia 2009*)

- Number of limitations
  - requires an expensive optimization procedure, and depends on a reasonable initialization
  - anticipate that it may be possible to learn the parameters from mocap data.

Thank you !