Optimal motion trajectories

Realistic character animation with control

Physically based motion transformation, Popović and Witkin

Synthesis of complex dynamic character motion from simple animation, Liu and Popović

Highly dynamic motion

Physically based motion transformation
**Motivations**

- Captured motion
  - rich and realistic but hard to edit
- Motion warping
  - works well only for small deformations
  - no high-level editing constraints

**High Level Control**

- Get a limp walk
  - by making one leg stiff
- “moon walk”
  - by reducing gravity
- “quite” run
  - by reducing the floor impact forces

**New Approach**

- Transform existing motion capture sequence
- Spacetime constraints formulation
- Get the best of both worlds:
  - expressiveness of captured data
  - controllability of the spacetime model

**Outline**

```
Original motion
```

```
Final motion
```

```
Reconstruction
```

```
Fitting
```

```
simplified model
```

```
complex model
```

```
Spacetime motion model
```

```
Transformed spacetime motion
```

```
Spacetime editing
```

```
+ +
```
**Character Simplification**

- DOF reduction improves performance and facilitates convergence
- The essence of the motion can be better preserved on a simplified model

**Approaches**

- Simplify character kinematics
- Use input motion to construct a spacetime motion model

**Simplified Kinematics**

- Remove irrelevant DOFs
- Reduce passive body structures to mass points
- Exploit symmetric movement of limbs

Human run  Human jump
**Motion Fitting**

- Handle: a property that correlates the original to the simplified model

![Diagram of motion fitting](image)

**Degrees of Freedom**

- Solve for simplified motion constrained by the handles
- Solve for muscle forces and contact forces that make the simplified motion satisfy dynamic constraints
  - muscle forces: \( Q_k = k_s(q_k - q_m) - k_d(q_k - q_m) \)
  - contact forces: \( Q_c = q \lambda \frac{\partial p}{\partial q} \)

**Constraints**

- Pose constraints
- Mechanical constraints
- Dynamics constraints

**Objective Function**

- Muscle smoothness
  \[ E_m = \dot{q}_m^2 \]
- Handle similarities
  \[ E_d = \left| h_o(q_o) - h_s(q_s) \right|^2 \]

\[ E = w_d \int E_d + \int E_m \]
Motion synthesis as constrained optimization

- DOFs: joint ($q_J$), muscle ($q_m$), and force ($q_F$) DOFs for simplified model
- Constraints: pose constraints, mechanical constraints, and dynamics constraints
- Objective function: muscle smoothness and handle similarities between complex and simplified models

Outline

Spacetime motion model

Spacetime editing

- Change pose and environment constraints
  - Foot placements and timing
  - Introduce a new obstacle
- Change the objective function
  - Minimize floor impact forces
  - Make dynamic balance more important

Spacetime editing

- Change explicit character parameters
  - Shorten a leg
  - Redistribute mass
  - Modify muscle characteristic
  - Gravity
**Outline**

- Original motion
- Final motion
- Spacetime motion model
- Transformed spacetime motion
- Fitting
  - + simplified model
- Spacetime editing
- Reconstruction

**Motion Reconstruction**

- Three different handle sets
  - Original motion handles ($h(q_o)$)
  - Spacetime fit handles (simplified model, $h(q_s)$)
  - Transformed spacetime handles ($h(q_t)$)
- Compute final motion handles
  - $h(q_f) = h(q_o) + (h(q_t) - h(q_s))$

**Minimum Displaced Mass**

- $E_{dm}(q_o, q)$ evaluates the total mass displacement when moving a character from pose $q_o$ to pose $q$

- $E_{dm} = \iiint \mu_i (p_i(q_o) - p_i(q))^2 \, dx \, dy \, dz$

**Motion Reconstruction**

- For each time $t$, solve $q_f$ that
  - minimizes $E_{dm}(q_o, q_f)$
  - subject to
    - handle displacement: $h(q_f) = h(q_o) + (h(q_t) - h(q_s))$
    - mechanical and pose constraints: $C(q_f) = 0$
EXAMPLE: HUMAN RUN

- Original model has 59 DOFs
- Simplified model has 19 DOFs
- Optimizations are done on one gait cycle
- Each optimization computes within 2 minutes

EXAMPLE: HUMAN BROAD JUMP

- Original model has 59 DOFs
- Simplified model has 11 DOFs
- Entire upper body reduced to a mass point
- No revolute joint angle

HOPPER

RESULTS

input mocap motion

simplified motion

Fitting

Editing

Reconstructing

reconstructed motion

edited motion
RESULTS

input mocap motion

simplified motion

Fitting

Editing

reconstructed motion

edited motion

DISCUSSIONS

- If you were the reviewer of this paper, can you think of two reasons to reject this paper?

- If you were the advisor of the author, what is the next task you would ask the author to do?

DISCUSSIONS

- The model simplification is done in an ad-hoc way. Can you think of an algorithm to do it in a more systematic way?

- Can this algorithm work with more lethargic or kinematics motion, such as picking up an object?

- Does this algorithm guarantee physical realism in the reconstructed motion?