On-line Puppetry: Issues and Solutions

Sung Yong Shin
Department of Electrical Engineering and Computer Science
Korea Advanced Institute of Science and Technology
http://cg.kaist.ac.kr

1. What is "On-line Puppetry"?

David Struman, Computer Puppetry, IEEE CG&A 18(1):38-45, 1998

Computer Puppetry

- Puppetry: Manipulating the posture of the puppet *directly*
  - ∴Motion Capture and Adaptation !!!
- Computer: Displaying a sequence of postures in real time

Bringing an inanimate object (puppet) into life.

On-line (Computer) Puppetry

On-line : Future data are not available

- Inherent nature of puppetry

(Off-line) Motion Retargetting

M. Gleicher, *SIGGRAPH '98*

"Off-line" is implicit in motion retargetting

On-line Motion Retargetting

Choi and Ko, *Pacific Graphics '99*

(Off-line) Motion Retargetting

Retargetting:

adapting the motion of an articulated figure to another figure with identical structure but different segment lengths

Spacetime Constraint Formulation [Gleicher 98]

- Interactive problem specification
  - Characteristic features to preserve
  - Spatial constraints
  - Temporal constraints
- Off-line: one large problem over the duration of motion

∴ look-ahead and -behind to avoid "jerkiness"

Clean input motion

On-line Puppetry: Issues

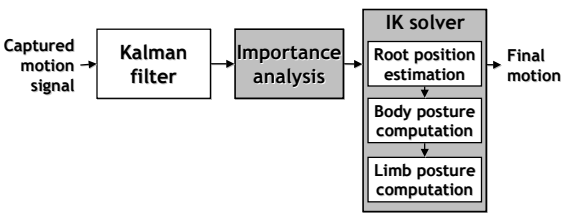
Automatic problem specification ⇦ Importance Analysis

On-line: A small problem at each frame

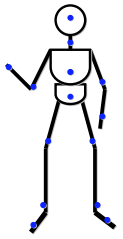
- Look-ahead ⇦ Importance Analysis
- Real-time performance ⇦ Real-time IK Solver

Noisy input motion ⇦ Kalman Filter

On-line Puppetry: Solution



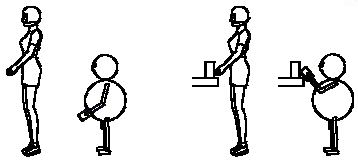
2. Importance Analysis



$$\mathbf{m}(t) = ((\mathbf{p}_0(t), \mathbf{q}_0(t)), (\mathbf{p}_1(t), \mathbf{q}_1(t)), \cdots (\mathbf{p}_n(t), \mathbf{q}_n(t)))$$

Which ones are important to preserve?

- The position of the root of the character
- ⇨ The joint angles
- ⇨ The positions of the end-effectors

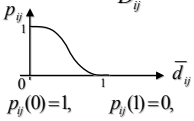


- If an end-effector interacts with an object in the environment, the position of the end-effector is important
- Otherwise, the joint angles on its corresponding limb are important

∴ The distance from an end-effector to the object gives a clue to determine what to preserve !!!

Importance Computation

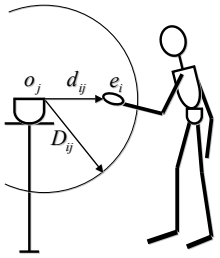
$$\bar{d}_{ij}(t) = \frac{d_{ij}(t) + \lambda \dot{d}_{ij}(t)}{D_{ij}}$$



$$p_{ij}(0) = 1, \quad p_{ij}(1) = 0,$$
$$\dot{p}_{ij}(0) = 0, \quad \dot{p}_{ij}(1) = 0$$

$$p_{ij}(\bar{d}_{ij}) = \begin{cases} 2\bar{d}_{ij}^{\,3} - 3\bar{d}_{ij}^{\,2} + 1, & \text{if } \bar{d}_{ij} \le 1 \\ 0, & \text{otherwise} \end{cases}$$

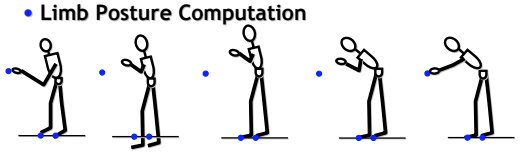
$$w_i = \max_j (\bar{p}_{ij})$$



3. Real-time Inverse Kinematics Solver

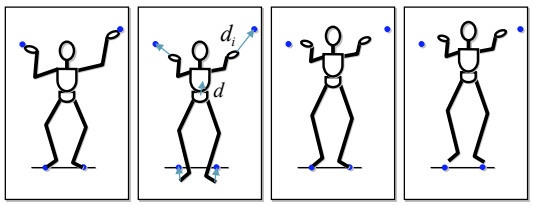
Three step approach

- Root Position Estimation
- Body Posture Computation
- Limb Posture Computation



Captured posture | Root position estimated | Body posture computed | Limb posture computed

3.1 Root Position Estimation



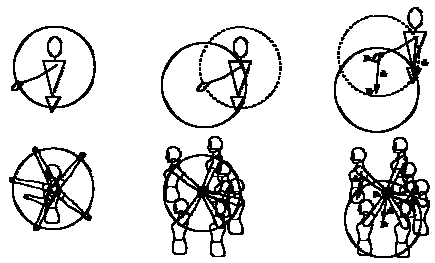
Captured posture

$$d = \frac{\Sigma w_i d_i}{\Sigma w_i}$$

Offsetting

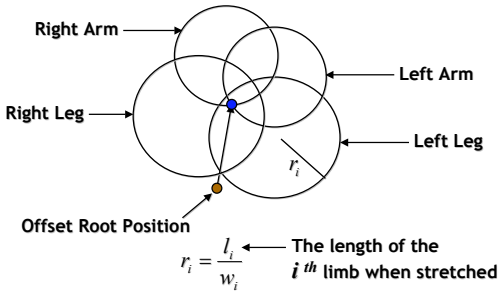
Adjustment
(a closest point problem)

Reachable Ranges



End-effector position | Shoulder position | Root position

Closest Point Problem



$r_i = \frac{l_i}{w_i}$ ← The length of the i^{th} limb when stretched

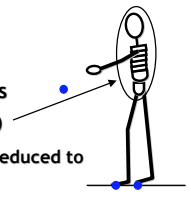
3.2 Body Posture Computation

Needed if the root position fails to make all end-effectors reachable to their goal

Body posture :

- Root position
- Root orientation
- Orientations of body segments

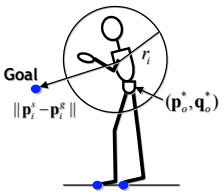
$(\mathbf{p}_0, \mathbf{q}_0, \mathbf{q}_1, \cdots, \mathbf{q}_n)$



For a rigid torso, this is reduced to

$(\mathbf{p}_0, \mathbf{q}_0, \mathbf{q}_1)$

Optimization Formulation



$r_i = \frac{l_i}{w_i}$

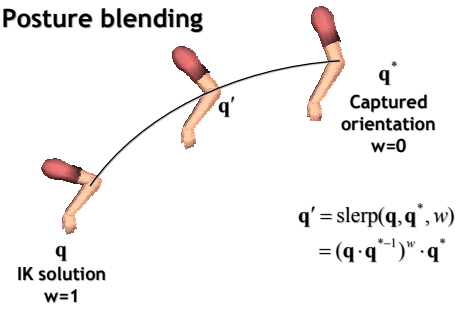
minimize $E = E_g + \alpha E_p$

$E_p = \gamma \| \mathbf{p}_0 - \mathbf{p}_0^* \|^2 + \sum \beta_j \| \ln(\mathbf{q}_j^{-1} \mathbf{q}_j^*) \|^2$

$E_g = \sum E_i$, where $E_i = \begin{cases} 0, & \text{if } \| \mathbf{p}_i^s - \mathbf{p}_i^g \| < r_i \\ (\| \mathbf{p}_i^s - \mathbf{p}_i^g \| - r_i)^2, & \text{otherwise} \end{cases}$

3.3 Limb Posture Computation

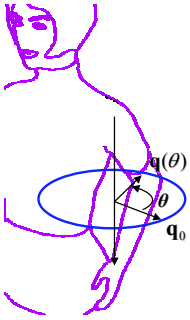
Posture blending



$$\mathbf{q}' = \mathrm{slerp}(\mathbf{q}, \mathbf{q}^*, w)$$
$$= (\mathbf{q} \cdot \mathbf{q}^{*-1})^w \cdot \mathbf{q}^*$$

Analytic Limb IK Solver

Elbow circle

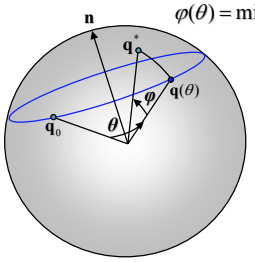


Give the swivel angle θ, the limb posture is analytically computed

Analytic Limb IK Solver

How to compute θ

minimize $\varphi(\theta)$



$$\varphi(\theta) = \min(\cos^{-1}(\mathbf{q}^* \cdot \mathbf{q}(\theta)), \cos^{-1}(-\mathbf{q}^* \cdot \mathbf{q}(\theta)))$$

where $\mathbf{q}(\theta) = e^{\frac{\theta \mathbf{n}}{2}} \mathbf{q}_0$

$\therefore |\mathbf{q}^* \cdot \mathbf{q}(\theta)|$ is maximized

$$\Big| k \sin\left(\frac{\theta}{2} + \alpha\right) \Big|$$

$\therefore$ θ can be compute analytically

4. Noise Filtering

Kalman filter: least square estimator for a linear system

However, the orientation space is not linear.

∴Locally linearize the orientation space !!!

Incremental orientation

- Euler angles [Welch et al 97]
- Rotation vector

$$\mathbf{q}_j(t) = e^{\mathbf{v}_j}\mathbf{q}_j(t-1)$$
$$\mathbf{v}_j = \ln\left(\mathbf{q}_j(t)\mathbf{q}_j^{-1}(t-\Delta t)\right)$$

- The state for the j^{th} sensor: $\mathbf{z}_j = (\mathbf{p}_j, \dot{\mathbf{p}}_j, \mathbf{v}_j, \dot{\mathbf{v}}_j)$

5. Discussion

- The importance of an end-effector guides what to preserve.
- It also gives how urgent the interaction of an end-effector with the environment.
  - ∴ Automatic constraint detection
- It has a limited look-ahead capability.
- The specialized IK solver maps the posture in real-time.

However, …

- The environment needs to be not too complex for real-time performance.
- The IK solver is specialized for human-like figures.

6. Conclusion and Future Work

Practical solution

KBS "Pang Pang", "Aliang"

Self-interaction

Non-human-like characters