6-DOF HAPTIC RENDERING

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6-DOF vs 3-DOF

* 3-DOF: point, position, force
* 6-DOF: object, position & orientation, force & torque

Friday, October 22, 2010

3DOF haptic rendering: virtual object A, 3D position p(input) ==> contact point p'(on A), contact force f(based on p,p').
6DOF haptic rendering: virtual object A, virtual object B(pos, ori <-- input) ==> multiple contact points, force and torque

Haptic Rendering Pipeline

* direct rendering
* virtual coupling

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short review, in case that Pete doesn't make it clear.
advantages & disadvantages of each

Ideal and Practical

* ideal solution:
    * position: constraint-based rigid body dynamics simulation
    * force-feedback: virtual coupling
* practical

Direct Rendering Approaches

* Gregory et al. 2000, Kim et al. 2003
* Johnson and Willemsen 2003, 2004, Johnson and Cohen 2001, Nelson et al. 1999

(Gregory et al. 2000)
6-DOF haptic display of polygonal models

- can be used on moderately complex polygonal models
- convex decomposition
- predictive collision response(fast update)
- force and torque interpolation

(Kim et al. 2003)
6-DOF haptic rendering using incremental and localized computations

- localized contact computation: guaranteed by high motion coherence due to fast force update & spatial locality near contact regions
- decompose surface, build hierarchies for fast proximity queries
- incremental method to estimate penetration depth
- clustering nearby contacts to speed up force determination

(Johnson and Willemsen. 2004) Accelerated haptic rendering of polygonal models through local descent

- local minimum distance(LMD) and spatialized normal cone hierarchies(SNCH)
- maintaining LMDs between models during movement
- each LMD less than cutoff distance is considered as a spring.

This algorithm will be detailed illustrated as an example for this set of methods.

Virtual Coupling with Object Voxelization

- McNeely et al. 1999
- Renz et al. 2001
- Wan and McNeely 2003

(McNeely. 1999)
6-DOF haptic rendering using voxel sampling

* enable manipulation modestly complex rigid object within an arbitrarily complex environment of static rigid object
* global voxel size, voxmap
* impedance-device and virtual coulper scheme
* penalty based

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This is the major paper to present in this set of methods.

(Wan and McNeely. 2003) Quasi-Static Approximation for 6-DOF haptic rendering

* Quasi-static approximation (QSA)
* solve for static equilibrium during each haptic time step
* stable

Rigid Body Dynamics with Haptic Feedback

* Impulse Dynamic Rigid Body Simulation
  * Chang and Colgate 1999
  * Constantinescu et al. 2004
* Constraint Based Rigid Body Simulation
  * Berkelman 1999
  * Ruspini and Khatib 2000
* Penalty Based Relaxed
  * McNeely et al. 1999
  * Wu 2000
  * Larsen 2001
  * Otaduy and Lin 2005

(Chang and Colgate. 1997) Real-time Impulse-based simulation of rigid body systems for haptic display

- based on virtual coupling(Colgate et al. 1995)
- based on impulse-based simulation
- heap of time-to-collide estimation, integration

(Ruspini and Khatib. 2000) The haptic display of complex graphical environments.

- using standard constraint-based position updating algorithm
- friction
- based on Baraff 1992

This paper will be a representation because it is simply using the standard methods.

Multi-resolution(LOD) Techniques

- Otaduy and Lin 2003
- Otaduy 2004

Recent Publications

* Kolensnikov and Zefran 2007 (penalty)
* Otaduy and Lin 2006 (penalty, LOD, linearized model)
* Barbic and James 2009(penalty, LOD, deformable)

* Thank you.