Fast and Reliable Contact Comput ations for Grasp Planning

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Forward Grasp Planning

1. Generate an approach direction
2. Find contact points
3. Measure the grasp quality
4. Repeat this process
Challenge

- Given grasp approaching directions
- Find all the contact points fast and reliably
Goal of Contact Computations

No Collision

Collision

Time of Contact (ToC)
Discrete Collision Detection

Collision Missing
Continuous Collision Detection (CCD)

- Motion trajectory $f(t)$ is known in advance.
Outline

• Continuous collision detection (CCD)
  – Convex
  – Non-convex
  – Polygon-soup
  – Articulated model
  – Deformable model

• Evaluation of CCD in grasp planning
Conservative Advancement (CA)

- Assume objects are *convex*
- Find the 1\textsuperscript{st} time of contact (ToC) of a moving object
Conservative Advancement (CA)

1. Find a step size $\Delta t_i$ to conservatively advance the object without collision
2. Repeat until inter-distance $< \varepsilon$

$ToC = t_1 + t_2 + t_3 + t_4$
Calculating $\mathbf{w}t$ in CA

$d, n$: closest distance, direction vector
$v$: velocity

$$
\int_0^{\Delta t} \left| \mathbf{n}(t) \cdot \mathbf{v}(t) \right| dt = \mu
$$
Calculating $t$ in CA

\[ \mu \Delta t \leq d \]

\[ \int_{0}^{\Delta t} |v(t) \cdot n(t)| \, dt \leq \max(\|v(t) \cdot n(t)\|) \, dt \leq d \]

\[ \therefore \Delta t \leq \frac{d}{\mu} \]
Extension to Non-convex [PG06]

- Use of convex decomposition

- Build a hierarchy of decomposed convex pieces and perform CA *hierarchically*
Santa vs. Thin Board

37K triangles
51,546 FPS
# of iterations 3.68
Bunny vs. Bunny

70K triangles/bunny  110 FPS  # of iterations 4.7
Torusknot vs. Torusknot

- 2.8K, 1067 FPS, # of iterations 4.49
- 11K, 400 FPS, # of iterations 4.49
- 34K, 186 FPS, # of iterations 4.46

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http://graphics.ewha.ac.kr
Extension to Polygon-Soups
[ICRA09]

• Swept Sphere Volume (SSV) [Larsen 1999]:
  – Point Swept Sphere (PSS)
  – Line Swept Sphere (LSS)
  – Rectangle Swept Sphere (RSS)
Controlling the Depth of BVH Traversal

![Graph](http://graphics.ewha.ac.kr)

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Results - Timings

Clubs:
- Without C²A: 4X
- With C²A: 28X

Gears:
- Without C²A: 4X
- With C²A: 28X

C²A  Without C²A

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Comparisons against [Zhang 06]

- [Zhang 06] can handle only manifold surfaces
Extension to Articulated Models [SIGGRAPH07]

- Treat each link as a rigid body
- Apply CA to each link independently
- Taking the minimum of CA results
Link Culling

1. Some links are collided later than others

2. Some links are not even collided during the entire time interval
Dynamic AABB Construction

• Idea
  1. Pre-compute AABBs for links
  2. Compute the AABBs of vertices of moving AABBs
  3. Compute the enclosing AABB
Dynamic AABB Construction

• Given a function $f(t)$, compute its tight-fitting AABB

• Easy way
  – Use interval arithmetic [Redon et al. 2004a,b]
  – Overshooting problem
Bounding Volume Culling

Interval Arithmetic

Taylor Models

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Locomotion Benchmark

- **CCD performance**
  - 1.22 msec
- **Mannequin**
  - 15 links, 20K tri
- **Obstacles**
  - 101K tri
- **Locomotion SW**
  - Footstep™
Exercise Benchmark

- **Mannequin**
  - 15 links, 20K triangles

- **Self-CCD performance**
  - 0.38 msec

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Motion Planning Benchmark

- **Excavator**
  - 52 links, 19K tri
- **Obstacles**
  - 0.4M tri
- **CCD performance**
  - 100~700 msec

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• Tower crane
  – 14 links, 1288 tri

• CCD performance
  – 5.66~15.1 msec
Extension to Deformable
[ICRA 2010]

• Point-wise linear interpolation

\[ p_t = (1 - t)p_0 + tp_1 \]
Extension to Deformable

\[
= \mu \\
\left( \max (\mu_p) + \max (\mu_q) \right) \cdot dt \leq d \quad \rightarrow \quad dt \leq \frac{d}{\mu}
\]
Deformable Motion Planning

Human Organs (14K triangles) [Rodriguez 06]
Deformable Motion Planning Benchmarks

**Human Organs**
- LA: 1000 ms
- Bar/Sheres: 100 ms

**Bar/Sheres**
- LA: 1000 ms
- Bar/Sheres: 100 ms

Timing (ms)
More on Deformable CCD

• Collision avoidance session
• Thursday, May 6th, 10:20 AM

• Continuous collision detection for non-rigid contact computations using local advancement
Software Implementations

• Source codes are available
  
  - [http://graphics.ewha.ac.kr/FAST](http://graphics.ewha.ac.kr/FAST)
  - [http://graphics.ewha.ac.kr/C2A](http://graphics.ewha.ac.kr/C2A)
  - [http://graphics.ewha.ac.kr/CATCH](http://graphics.ewha.ac.kr/CATCH)
Grasp Planning

- Decomposed into hand movement part and finger closing part
Grasp Planning

- Extent of the finger links’ motion are pre-computed and used to cull the objects that are far from the robotic hand.

Hand Moving

Finger Closing
Experimental Results

• Three settings
  – Standalone
  – Bimanual grasping
  – Grasping in complex environment

• Based on GraspIt!
Experimental Results

- CATCH is $4 \sim 10$ times faster than the extended PQP in GraspIt!
- At least 10 grasp candidates can be tested within one second

<table>
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<tr>
<th>Experiment</th>
<th>$T_{\text{moving}}$ (msec)</th>
<th>$T_{\text{closing}}$ (msec)</th>
<th>$T_{\text{ray}}$ (msec)</th>
<th>$N_1$</th>
<th>$N_2$</th>
<th>$T_{\text{total}}$ (msec)</th>
<th>$Q_{\text{best}}$</th>
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<td>3</td>
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Real Robot Execution
Conclusions

• Fast and reliable CCD methods
• Application to forward grasping

• Future work
  – Deformable grasping
  – Fast (real-time?) grasping using graphics hardware
Acknowledgements

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Thank you for listening!

http://graphics.ewha.ac.kr
Rigid Body Dynamics

1996 FPS

529 FPS
Articulated Body Dynamics Benchmark

• Four trains
  – 10 links, 23K tri (each)

• CCD performance
  – 535 msec