Functional Analysis of Finger Contact Locations during Grasping

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Human grasping strategies

• The human hand: the most versatile end-effector known!
  ▪ wide range of configurations and subtle adjustments

• What about strategies during grasping?
  ▪ modulation of applied fingertip force or finger impedance
    [Santello and Soechting ’00, Reilmann et al. ’01, Gao et al. ’06, etc.]
  ▪ choice of contact locations
    [Cohen and Rosenbaum ’04, Lukos et al. ’07,’08, etc.]
  ▪ and a gradient of strategies in between!

• Choice of grasping strategy is complex
  ▪ depends on many factors (size, force, dexterity, etc.)
  ▪ and not well understood
Contact location vs. force modulation

- Problem: we can study one at a time, but usually not both!
  - most 6D force sensors restrict choice of contacts
- Our method: functional analysis of contact points
  - we don’t know what forces users generate
  - but we can compute what forces they can generate
  - study the interplay between contact locations and force
- Potential applications
  - tactile interfaces: also limit choice of contact location
  - force feedback: can we design better interfaces?
Functional analysis of contact locations

- Grasp Wrench Space (GWS) – unit sum magnitude
  - space of wrenches $w = \begin{bmatrix} f & \tau \end{bmatrix}^T \in \mathbb{R}^6$ that a grasp can apply
  - mirror image of the space of disturbances that can be resisted
  - built as a function of contact locations, surface normal, and friction cone approximation
Building the Grasp Wrench Space

- Start from individual contacts – assume sum = 1 (Unit)
  - Build the friction cone
  - Translate to the center of the object
- Convex hull of individual contact wrenches gives GWS
  - 6D – we can not visualize it directly
  - use 3D halfspace intersections

3D grasp force space
Grasp Wrench Space Example
Grasp Quality Metrics

- $Q_w$ – amount of force needed to resist a **particular** disturbance
  - **smaller is better**
- $Q_\varepsilon$ – highest $Q_w$ across **all** possible disturbances
- Capture whether the choice of contact points makes it easier or harder to resist disturbances
Experimental setup

- allows choice of contact normal orientations
- samples 3D disturbance wrench space
- blocks / allows visual cues
Experimental setup

- allows choice of contact normal orientations
- samples 3D disturbance wrench space
- blocks / allows visual cues
Experimental setup

- 4 possible weight distributions:

- Task: lift object and minimize roll
  - enforce the use of tripod grasps

- One set consisted of 10 trials:
  - **blocked** – with the same weight distribution
  - **random** – with random weight distributions
  - 6 subjects, 4 sets of trials in each condition

- Track fingertips to obtain contact point locations
Results – Grasp quality analysis

Grasp Capture
Results – Grasp quality analysis

Grasp Capture

Grasp Reconstruction
Results – Grasp quality analysis

Grasp Capture → Grasp Reconstruction → Grasp Quality
Results – Grasp quality analysis

Grasp Capture  \rightarrow\  Grasp Reconstruction  \rightarrow\  Grasp Quality

Inside \textit{GraspIt}!
Results – modulation of contact location

- Standard deviation of contact point location over all 20 trials
  - modulation of contact points is present
  - but at different degrees across subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>AD</th>
<th>MA</th>
<th>JW</th>
<th>WH</th>
<th>QF</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. stdev. in x,y,z (mm)</td>
<td>14.96</td>
<td>7.87</td>
<td>15.98</td>
<td>19.00</td>
<td>11.00</td>
<td>7.53</td>
</tr>
</tbody>
</table>

Diameter: 68.8 mm
Results – adaptation to known disturbance

- Comparison: **random set** vs. **blocked set**

\[ Q_w \] – amount of force needed to resist a particular disturbance **smaller is better**
Results – adaptation to known disturbance

- **Blocked** set comparison: first vs. rest of set

3 subjects (AD, MA and JW)

3 subjects (WH, QF and SI)
Discussion

- Is choice of contact points explained by easier resistance?
  - yes, but only with some subjects
- What strategies did the other subjects choose?
  - maybe also modulating contact force
  - we should measure both position and force
- Design tasks that better discriminate between strategies:
  - larger / heavier objects
  - behavioral consequences (e.g. avoid spill)
- Also measure task performance (i.e. object roll)
  - markers on object surface
Conclusions

- Tool for functional analysis of contact point locations
  - contact geometry and force generation capabilities
  - based on Grasp Wrench Space
- Enables wide range of experiments and applications
  - designed experiment to investigate 3D choice of contacts
- Users behavior was partially explained through analysis

**Note**: GWS computations performed using our *GraspIt!* simulator
- publicly available:
Thank you!