Functional Evaluation of Grasping and Manipulation Performance

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Workshop on Anthropomorphic Robotic Hands: Design and Control
IEEE-RAS Int. Conf. Humanoid Robots
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I. INITIAL THOUGHTS
Human hand functionality

- Gestures
- Grasping
- Manipulation
- Exploration
Multifingered hands

General purpose multi-finger hands

Simple grippers

Adaptive underactuated hands
Two finger grippers vs. Multifingered hands

- Number of DOFs
- Manipulation abilities
- Cost
- Control complexity

Applications in industry
Robustness
II. PERFORMANCE MEASURES
Comparison of capabilities

Physical characteristics

[Belter et al., JRRD’13]
Comparison of capabilities

Index of Anthropomorphism:

Overlap of cartesian workspaces
[Liarkapis et al., ICRA’13]

Overlap of reduced fingertip workspaces
[Feix et al., TRO’13]
Functional evaluation of grasps

Grasp taxonomy

[Cutkosky, TRA, 89]
Functional evaluation of grasps

Grasp taxonomy

<table>
<thead>
<tr>
<th>Power</th>
<th>Intermediate</th>
<th>Precision</th>
</tr>
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<tbody>
<tr>
<td>Palm</td>
<td>Side</td>
<td>Pad</td>
</tr>
<tr>
<td>3-5</td>
<td>2</td>
<td>2-3</td>
</tr>
<tr>
<td>2-5</td>
<td>2-3</td>
<td>2-4</td>
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</tbody>
</table>

[Feix, RSS’09; Grebenstein, Springer’13]
Evaluation of precision grasp capabilities

Kapandji test

[Kapandji, Chirurgie de la Main, 86]
Evaluation of precision grasp capabilities

Kapandji test:
-used for evaluation of pollicization

[Toshihiko Ogino, Hokushin-Higashi Hospital]
Evaluation of precision grasp capabilities

Functional workspace

[Kuo et al., J. Electromy. And Kines., 09]
Evaluation of fine manipulation capabilities

A taxonomy for manipulation

[Bullock et al., Tr. haptics, 13]
Evaluation of fine manipulation capabilities

Manipulation workspace & range of manipulation

Two-finger workspace

Three-finger workspace

[Bullock et al., HAPTICS, 14]
Evaluation of fine manipulation capabilities

Manipulation workspace & range of manipulation

1. Initial position of the object
2. Find a FC grasp
3. Manipulate in the desired DoF until reaching joint limits or losing FC
III. CASE STUDY
Experimental approach: modular testbed

DLR/HIT hand II

7 different thumb placements
(Thumb location is fixed)

I-50, I-60, I-70
M-50, M-60, M-70

Original

[Roa et al., ICRA 2014]
Experimental approach: modular testbed

Why only the thumb?

Typical coverage of insurances

<table>
<thead>
<tr>
<th>Description</th>
<th>% of Amount of Insurance</th>
<th>Description</th>
<th>% of Amount of Insurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of Life</td>
<td>100%</td>
<td>Loss of index finger</td>
<td>10%</td>
</tr>
<tr>
<td>Loss of two limbs</td>
<td>100%</td>
<td>Loss of middle finger</td>
<td>6%</td>
</tr>
<tr>
<td>Loss of both hands, or all fingers and both thumbs</td>
<td>100%</td>
<td>Loss of ring finger</td>
<td>5%</td>
</tr>
<tr>
<td>Loss of both feet</td>
<td>100%</td>
<td>Loss of little finger</td>
<td>4%</td>
</tr>
<tr>
<td>Total loss of sight or both eyes</td>
<td>100%</td>
<td>Loss of metacarpals—1st and 2nd</td>
<td>(add'l) 3%</td>
</tr>
<tr>
<td>Injuries resulting in being permanently bedridden</td>
<td>100%</td>
<td>3rd, 4th and 5th</td>
<td>(add'l) 2%</td>
</tr>
<tr>
<td>Any other injury causing permanent total disablement</td>
<td>100%</td>
<td>Loss of leg at or above the knee</td>
<td>60%</td>
</tr>
<tr>
<td>Loss of arm or above elbow</td>
<td>70%</td>
<td>Loss of leg below knee</td>
<td>50%</td>
</tr>
<tr>
<td>Loss of an arm between elbow and wrist</td>
<td>60%</td>
<td>Loss of one foot</td>
<td>50%</td>
</tr>
<tr>
<td>Loss of hand</td>
<td>50%</td>
<td>Loss of toes—all of one foot</td>
<td>25%</td>
</tr>
<tr>
<td>Loss of four fingers and thumb of one hand</td>
<td>50%</td>
<td>Loss of big toe</td>
<td>25%</td>
</tr>
<tr>
<td>Loss of four fingers</td>
<td>35%</td>
<td>Loss of any toe other than big toe, each</td>
<td>1%</td>
</tr>
<tr>
<td>Loss of thumb</td>
<td>15%</td>
<td>Loss sight of one eye</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of hearing—both ears</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loss of hearing—one ear</td>
<td>25%</td>
</tr>
</tbody>
</table>
Evaluation results

Kapandji test
Evaluation results

Kapandji test
### Evaluation results

#### Kapandji test

<table>
<thead>
<tr>
<th></th>
<th>M-50°</th>
<th>M-60°</th>
<th>M-70°</th>
<th>I-50°</th>
<th>I-60°</th>
<th>I-70°</th>
<th>Orig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-D</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>I-I</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<td>✔</td>
</tr>
<tr>
<td>I-P</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>M-D</td>
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<td>✔</td>
</tr>
<tr>
<td>M-P</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>R-D</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<td>✔</td>
</tr>
<tr>
<td>R-I</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>R-P</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>L-D</td>
<td>x</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<td>✔</td>
</tr>
<tr>
<td>L-I</td>
<td>x</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<tr>
<td>L-P</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

- $P_1$:
  - 6
  - 8
  - 7
  - 6
  - 6
  - 5
  - 12

- Rank:
  - 4 (tied)
  - 2
  - 3
  - 4 (tied)
  - 4 (tied)
  - 7
  - 1

### Functional workspace [cm³]

<table>
<thead>
<tr>
<th></th>
<th>M-50°</th>
<th>M-60°</th>
<th>M-70°</th>
<th>I-50°</th>
<th>I-60°</th>
<th>I-70°</th>
<th>Orig.</th>
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</thead>
<tbody>
<tr>
<td>Index</td>
<td>11.51</td>
<td>3.60</td>
<td>0.47</td>
<td>47.58</td>
<td>30.52</td>
<td>18.58</td>
<td>35.59</td>
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<tr>
<td>Middle</td>
<td>55.76</td>
<td>40.26</td>
<td>27.29</td>
<td>3.89</td>
<td>0.72</td>
<td>0.42</td>
<td>33.79</td>
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<tr>
<td>Ring</td>
<td>10.91</td>
<td>3.20</td>
<td>0.46</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.80</td>
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<tr>
<td>Little</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.003</td>
</tr>
</tbody>
</table>

- $P_2$:
  - 78.17
  - 47.07
  - 28.23
  - 51.46
  - 31.24
  - 19.01
  - 75.18

- Rank:
  - 1
  - 4
  - 6
  - 3
  - 5
  - 7
  - 2
Evaluation results

Fine manipulation:
3 balls
(diam 20, 35, 42.5mm)
Evaluation results

Fine manipulation: simulation

I-50

M-60

Size: transl. cap.
Evaluation results

Fine manipulation:

Compromise between thumb position and “ideal” object size
IV. FOOD FOR THOUGHT
Towards a functional evaluation: grasping

Is grasping wrongly defined?

[The French Cuisine, Julia Child]
[Credit: Oliver Brock, Matt Mason]
Towards a functional evaluation: in-hand manipulation

Video: Extrinsic dexterity

[Chavan et al., ICRA’14]
Towards a functional evaluation: benchmarks...

Benchmark: “precisely defined, standardized tasks” with some numerical evaluation

SHAP (Southampton Hand Assessment Protocol)  
Grooved pegboard test

6 grasps, 14 tasks
Towards a functional evaluation: contests…

Amazon Picking Challenge @ ICRA’15
Discussion

-No apparent relation between grasp and manipulation performance using typical measures

-Measures can be biased towards anthropomorphic designs
  -Anthropomorphism and dexterity seem to be orthogonal…

-Where to draw the line between intrinsic and extrinsic functionality? between hand and arm/hand manipulation?

-How to properly benchmark grasping/in-hand manipulation?:
  -Databases, performance metrics, test procedures
  -Physical fitness, perceptual, planning & control abilities, awareness
Thanks!

Please share your thoughts!