Santos Hand Simulation

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Presentation Outline

- Current Hand Capabilities
- Ongoing Hand Research
- Future Work
Current Capabilities

✓ Biomechanical Model
  • Right Hand
  • Left hand

✓ Graphical Interface
  • Scalable Anthropometry

✓ Photorealism (and Skin deformation)

✓ Grasping (16 power and precision grasps)

✓ Grasp Morphing (changing of grasping from one to another)

✓ Manipulation (individual joints, or coupled joints)

✓ Forward Kinematics

✓ Joint Torque Analysis

✓ Reach Envelopes of each Finger
Ongoing Research

- Graphical Interface
- Finger Pressure
- Finger Wrapping
- Grasping Quality Calculation
Future Work

- Validation
- Grasp Artificial Intelligence
- Local Biomechanics wrist and hand modeling
- Compliant Pressure Mapping
- Evaluation of Carpal Tunnel Pressure
- Dexterity Analysis
The hand is an extension of the human brain

Immanuel Kant
Current Capabilities

Hand Model

NOTE: The thumb is reversed.
Current Capabilities

Hand Model

Left Hand

Right Hand
Current Capabilities

Grasping Interface (16 Styles)

- Power
  - Non-Prehensile
  - Prehensile
    - Prismatic
    - Circular
  - Circular
  - Prismatic

Morph Between Grasps

Morph to Neutral

Apply To:
- Left Hand
- Right Hand
- Both Hands

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<th>Fist</th>
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Forward Kinematics

Current Capabilities
Optimization-based method

Find: $q^i$

Minimize: $f_d = \sum_{i=1}^{n} w_i |q_i - q_i^N|$

Subject to:
$q_j^{iL} \leq q_j^i \leq q_j^{iU}$

$\|p^i - x_p^i\| = 0$
Finger Workspace

D-H Table

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<td>0</td>
<td>$l_{r1}$</td>
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<td>5</td>
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Range of motion

95% Male HB=90 mm, HL=190 mm

Two views of workspace for thumb

Current Capabilities
$$\mathbf{\tau} = \sum_k \mathbf{J}_k^T \mathbf{F}_k$$

Where

$$\mathbf{\tau} = [\tau_1, \tau_2, \ldots, \tau_n]^T$$

$$\mathbf{J}_k(q) = \begin{bmatrix} \frac{\partial T_1(q)}{\partial q_i} r_k & \cdots & \frac{\partial T_i(q)}{\partial q_i} r_k & \cdots & \frac{\partial T_k(q)}{\partial q_k} r_k \\ Z_0(q) & \cdots & Z_{i-1}(q) & \cdots & Z_{k-1}(q) \end{bmatrix}_{6 \times k}$$
Current Capabilities

Joint Torques

Contact force for each segment is 1N
Current Capabilities

Joint Torques

Joint Torques (N.m)

Torque

Joint

-0.4
-0.2
0
0.2
0.4
0.6
0.8

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Graphical Interface for Hand
Recursive method:

\[ \tau_1^n = f_1(q_1, q_2, \ldots, q_n, F_n) \]
\[ \tau_2^n = f_2(q_1, q_2, \ldots, q_n, F_n) \]
\[ \vdots \]
\[ \tau_n^n = f_n(q_1, q_2, \ldots, q_n, F_n) \]

Given one of \( \tau_1^n \) \ldots \( \tau_n^n \)

Solving above equations to find the rest of \( \tau_i^n \) and \( F_n \)

Repeat the above procedure to find all other finger pressures
Joint Torque

-0.25
-0.15
-0.05
0.05
0.15
0.25
0.35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Joint
Torque (N.m)

Finger contact forces: 3.5N, 4.0N, 2.5N, 3.0N, and 2.5N
Finger contact forces: 2.5N, and 2.5N
Spherical Sensors

- Simplified Collision Detection
- Finger Wrapping
Finger Wrapping
Given: Object Model, Hand Model, Grasp

Find: The quality of the grasp
- **Given**: Object Model, Contact points

- **Find**: Space of forces and torques that can be exerted on the object
Constraints:

- Can exert both tangential and normal forces.
- Fingers must not slip!
Linear FC Approximation

For $m = 4 \rightarrow 30\%$ error

For $m = 8 \rightarrow 8\%$ error
\[ w_i = \left( \begin{array}{c} f_i \\ D_i \times f_i \end{array} \right) \]

Definition of a wrench (6-dimensional)

\[
\sum_{j=1}^{j=m} \alpha_j \cdot f_j
\]

Friction Pyramid Approximation

\[
W = \left\{ w \mid w = \sum_{i=1}^{n} \sum_{j=1}^{m} \alpha_{ij} w_{ij} \right\}
\]

\[ W_{L1} = \text{ConvexHull} \left( \bigcup_{i=1}^{n} \left\{ w_{i1}, w_{i2}, \ldots, w_{im} \right\} \right) \]
Implementation

Sim Engine
- Normals
- Contact points
- COM

C++
- Friction Cones
- Compute wrench space
- Assume COF

QHull
- Convex Hull Computation
- List of planes

C++
- Compute quality from list of planes

Quality
What Do they Mean in Reality?

Measure#1:
Radius of inscribed sphere

Measure#2:
The volume of the convex hull

3D Force-Space Projection of Original 6D Hull
Future Work

- Validation
- Evaluation of Carpal Tunnel Pressure
- Grasp Artificial Intelligence
- Local Biomechanics wrist and hand modeling
- Compliant Pressure Mapping
- Dexterity Analysis
Future work

Validation model: Motion Capture
Future work

Carpal tunnel syndrome
Cost function:

Pronation/supination angles
Metacarpophalangeal (MP) angle
Wrist angles (flexion/extension)
Wrist angles (radial/ulnar)
Fingertip loads
Future Goals

Grasping

- Grasp Quality
  - Learning
    - Pattern Recognition
    - Neural Nets
  - Optimization
    - Maximize Quality
    - Constraints
### Cost Function for the Hand Model

1. **Biomechanical Model**
   - Keir, et al. (1998, 1999),
   - Szabo and Chidgey (1989),
   - Weiss (1995),
   - Guo, et al. (2005),
   - DeKrom, et al. (1990),
   - Zatiorsky, et al. (2000, 2001)

2. **Forward Kinematics**
   - Gonzalez, Buchanan, Delp (1997)
   - Matias, et al. (1998),
   - McCauley and Crumpton (1997),
   - Delp, et al. (1996)
   - Dannion, et al. (2001)
   - Gelberman, et al. (1981),
   - Rydevik and Lundborg (1977),
   - Werner and Armstrong (1997),
   - Deshpande, et al. (1997),
   - Neiman, et al. (1995),
   - Tarinelli and Nowak (1999)
   - Li, et al. (1999, 2004a, 04b, 05)

3. **Graphical Interface**

4. **Photorealism (and Skin deformation)**

5. **Manipulation (individual joints, or coupled joints)**

6. **Grasping (16 power and precision grasps)**

7. **Grasp Morphing (changing of grasping from one to another)**

8. **Grasp Artificial Intelligence**

9. **Finger Pressure**

10. **Joint Torque Analysis**

11. **Local Biomechanics wrist and hand modeling**

12. **Compliant Pressure Mapping**

13. **Reach Envelopes of each Finger**

14. **Evaluation of Carpal Tunnel Pressure**

15. **Dexterity Analysis**
Artificial Intelligence

- Decision making
- Emotion-based cognitive functions
- Robotics-like task planning
- Computer modeling of cognitive aspects
Grasping (Direct Manipulation)
Hand Models and Grasping

NOTE: The thumb is reversed.

Plane Abd/Add

Plane F/E
Geometric-based Grasping
Field System: Tactical Decision Aid
Hand Modeling
Hand Zone
Differentiation
Body Zone Differentiation, analyzed from the same Hand Zone End Effector
Thank you

Santos

TM