NATURAL GRASPING WITH A HUMANOID ROBOTIC HAND

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Problem statement

Natural grasping from robotic hand
1. Make a human-like robotic hand (Robot: A programmable & movable mechanical structure)
2. Human-like grasping by robotic hand

Application and impact:
Robotic hand grasping in unconstructed environment – for Humanoid robot (or robotic arm), prosthetic hand and industrial area

Nadine’s original hand is not articulated
Challenges

The requirements of the robotic hand

• Static - Looks like human hand in Shape, colour, hardness and texture
How to create the inside structure and outside skin for the robotic hand?

• Dynamic - Moves like human hand in Degree of freedom (DOF), Range of motion (ROM), friction, move accuracy and speed.
How to precisely simulate the dynamic of human hand?

• Finger synergy and in-hand manipulation
How to precisely simulate a complex manipulation?
State-of-the-art

Hand functionality oriented
- Degree of freedom (DOF)
- Range of Motion (ROM)

[1] Photograph by Ariel Adams
State-of-the-art(2)

Anatomically Correct
-Finger bones
-Ligament, tendon, sheaths...

Teleoperation of the biomimetic robotic hand

The Anatomically Correct, Biomechatronic Hand

Human Finger anatomy and motion range

Middle finger anatomy without pulley system[1]

Under-actuated + Over-actuated

Soft Body Robot


Our method

Which approach is better? What is missing?

- Deformable tissue
- Customize and fast 3D modelling

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That is, let $P$ denote the point set of one of the template phalanx models, and $\mathbf{p} = [p_x, p_y]^T \in P$ be an arbitrary point, the corresponding coordinates of $\mathbf{p}$ in the local coordinate system of the customized phalanx model, $\mathbf{p}'$, is calculated as follows:

$$\mathbf{p}' = R(\theta)S(\lambda)\mathbf{p}.$$  \hfill (1)

where $R(\theta)$ is the rotation matrix parametrized by $\theta$, the counterclockwise angle of rotation with respect to the $x$ axis:

$$R(\theta) = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix}.$$  \hfill (2)

And $S(\lambda)$ is the uniform scaling matrix with the scaling factor $\lambda$:

$$S(\lambda) = \begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix}.$$  \hfill (3)

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Left: The surface model captured by 3D scanning. Right: The anatomy of the human hand. 25 landmarks are labeled to locate joints and phalanges.
3D modelling of tissue

create a flexible figurine [1]

(i) Hull generation
(ii) Structure hollowing
(iii) Deformation curve fitting

Top: The process of modeling the tissue layer as a tube structure. We shrink the surface model while expand the phalanx layer to obtain the hull of the tissue layer. Middle: Demonstration of tissue tubes with different thickness. Bottom: Supports used to stabilize the structure.

Deformation test
Finger design

Demonstration of the motion control system of our robotic hands. Circle 1-7 denote structures used in our previous method. With the proposed multi-layer design, the system is simplified (remaining structures are labeled in green) to reduce the complexity and cost.
Comparison

Comparison of the proposed design with other anthropomorphic robotic hands. Materials refer to 3D printing materials and E-motor stands for electric motor.

<table>
<thead>
<tr>
<th>Model</th>
<th>Year</th>
<th>Materials and Components</th>
<th>Actuator</th>
<th>Joint Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shadow hand</td>
<td>2007</td>
<td>N.A. Metallic structures</td>
<td>E-motor + tendon</td>
<td>Hinge joint</td>
</tr>
<tr>
<td>RBO hand V2</td>
<td>2015</td>
<td>N.A. Soft materials</td>
<td>Pneumatic motor</td>
<td>Expansion Bending</td>
</tr>
<tr>
<td>Soft robotic hand</td>
<td>2015</td>
<td>N.A. Soft materials</td>
<td>Shape memory alloy</td>
<td>Bending or Stretching</td>
</tr>
<tr>
<td>Biomimetic hand</td>
<td>2016</td>
<td>N.A. Rigid materials</td>
<td>E-motor + tendon</td>
<td>Ligaments</td>
</tr>
<tr>
<td>ACB hand</td>
<td>2019</td>
<td>N.A. PolyJet, resin</td>
<td>E-motor + tendon</td>
<td>Ligaments</td>
</tr>
</tbody>
</table>


Grasping test and comparison

- Large Diameter
- Small Diameter
- Medium Wrap
- Adducted Thumb
- Light Tool
- Prismatic 4 Finger
- Prismatic 3 Finger
- Prismatic 2 Finger
- Palmar Pinch
- Power Disk
- Power Sphere
- Precision Disk
- Precision Sphere
- Tripod
- Fixed Hook
- Lateral
- Ventral
- Extension Type
- Distal Type
- Writing Tripod
- Tripod Variation
- Parallel Extensio
- Adduction Grip
- Tip Pinch
- Lateral Tripod
- Sphere 4 Finger
- Quadpod
- Sphere 3 Finger
- Stick
- Palmar
- Ring
- Index Finger Extension
- Inferior Pincer

- Our robot hand
- InMoov hand
- Nadine’s hand Version 4
Grasping test and comparison (2)
Design and making of our robotic hand
Grasping test
In-hand manipulation

Dexterous manipulation sub-categorization. Tasks are further classified by their principal axis of motion

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