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# APPROACHING HUMAN HAND DEXTERITY THROUGH HIGHLY BIOMIMETIC DESIGN

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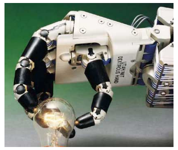
# Magician's Hand Manipulation Tricks

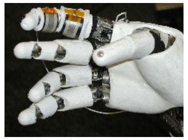

Magician Peter Pitchford **http://www.magicbymanipulation.com/**

# Why Anthropomorphic Robotic Hands?

By choosing five-fingered robotic hand design, researchers want to easily transfer knowledge of dexterous hand movements from human to robot

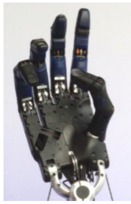


**UTAH/MIT Hand (1983)**



**Robonaut (1999)**

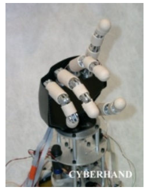
**Gifu Hand (2001)**



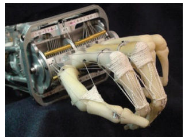
**Shadow Hand (2004)**

**Keio Hand (2005)**

**Naist Hand (2005)**

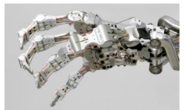



**Cyber Hand (2006)**

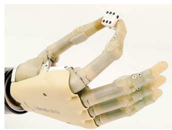


**ACT Hand (2009)**


**ELU-2 Hand (2010)**



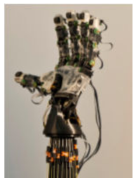
**DLR Hand (2011)**



**i-Limb (2009)**


**BeBionic Hand (2012)**

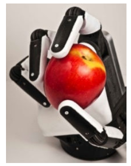
**JHU Hand (2012)**



**UB Hand IV (2012)**

**UW Hand (2012)**

**Soft Hand (2012)**



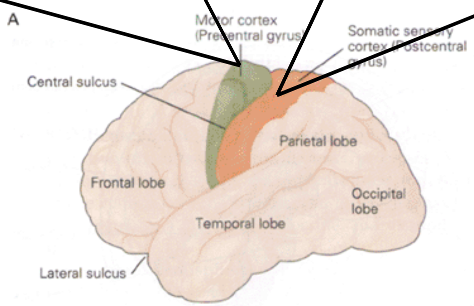
**Sandia Hand (2013)**

**RBO Hand 2 (2014)**

# Using Brain to Control Anthropomorphic Robotic Hands

Cortical homunculus shows how human brain sees the body from the inside

Motor homunculus




Sensory homunculus

(Principles of Neural Science, 4th_Edition)

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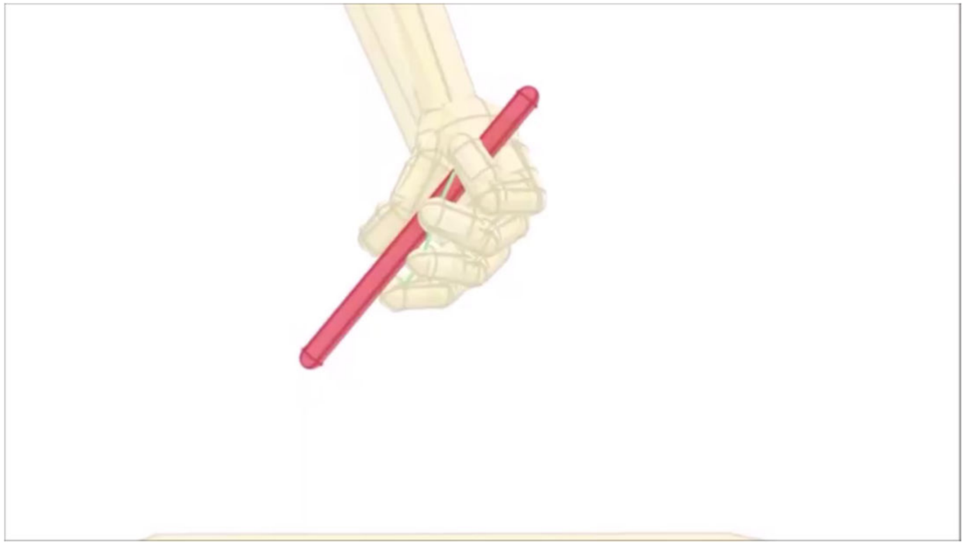
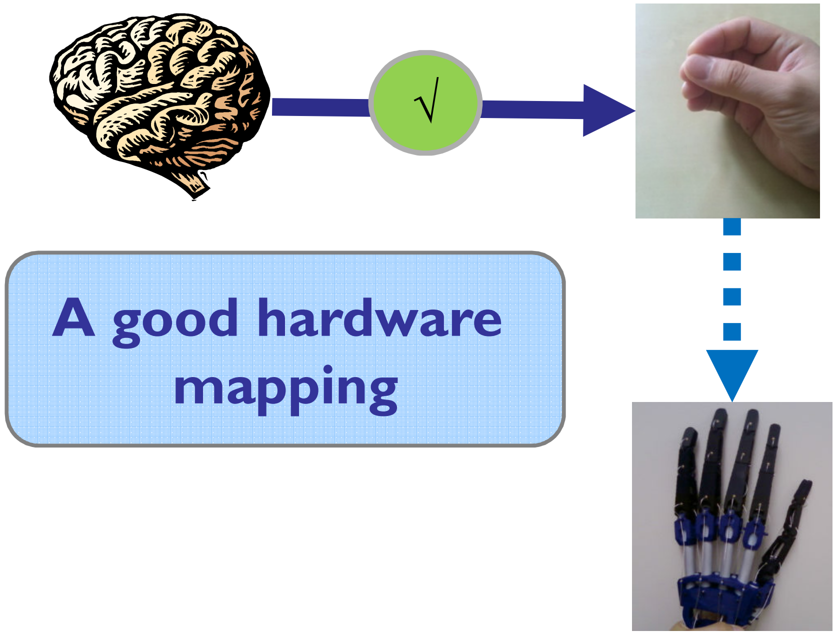
# Autonomous Control of Anthropomorphic Robotic Hands



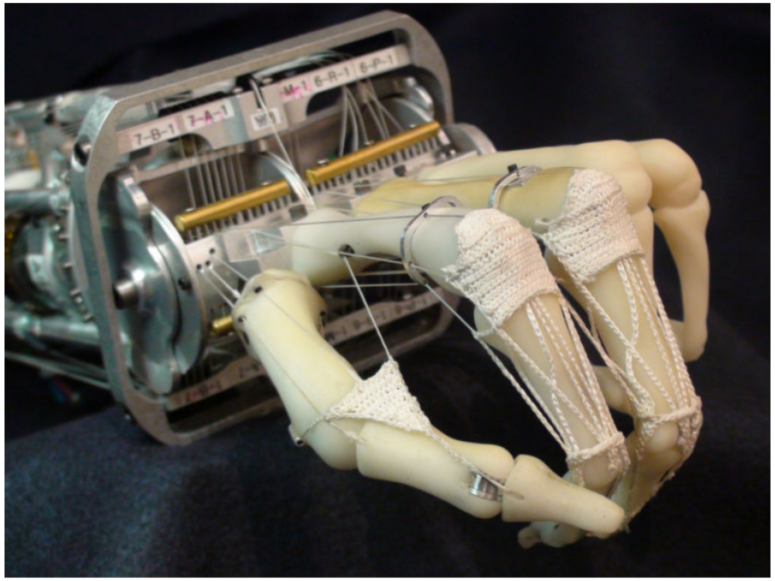
Movement Control Lab, University of Washington (Mordatch et al., 2014)

# Tele-manipulation: A Practical Way to Extract Hand Dexterity from Brain




Avatar, 2009

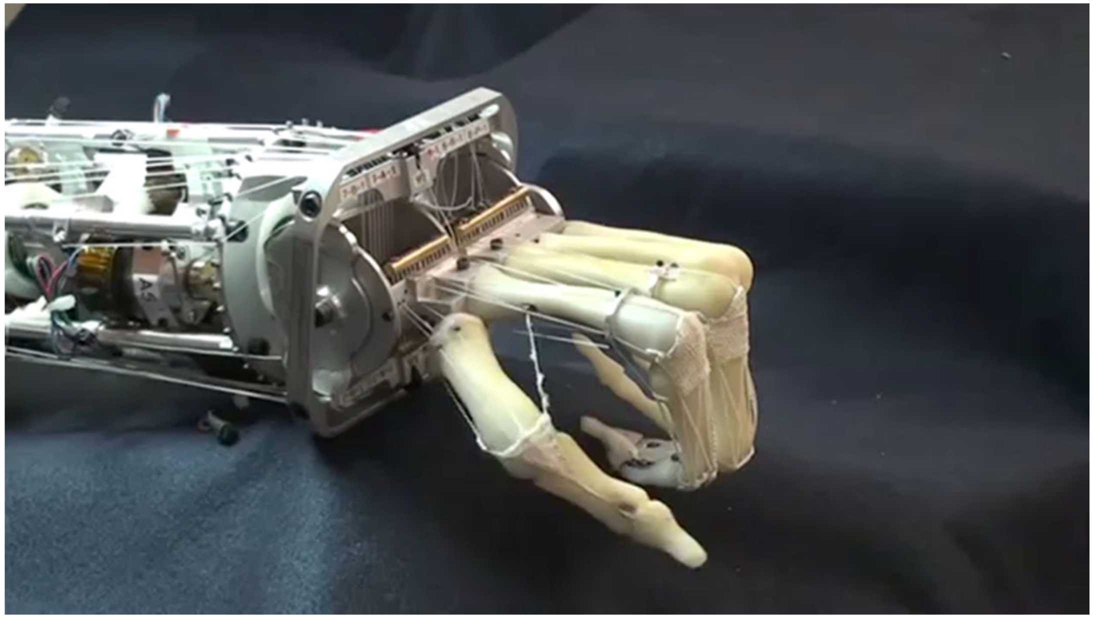
# The Anatomically Corrected Test-Bed (ACT) Hand



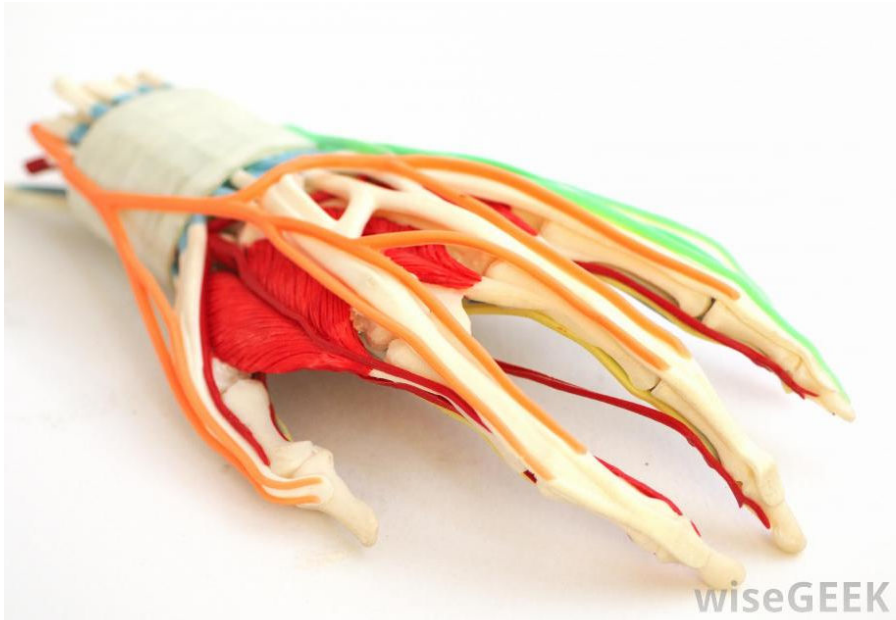
Mimics:

- Bone structure
- Tendon routings
- Joint DOFs
- Muscles
  - 6 motors the fingers
  - 8 motors for thumb
  - 4 motors for wrist

# Thumb Flexion Motion of The ACT Hand



# Important Biomechanical Features Need to Be Mimicked




http://www.wisegeek.org/

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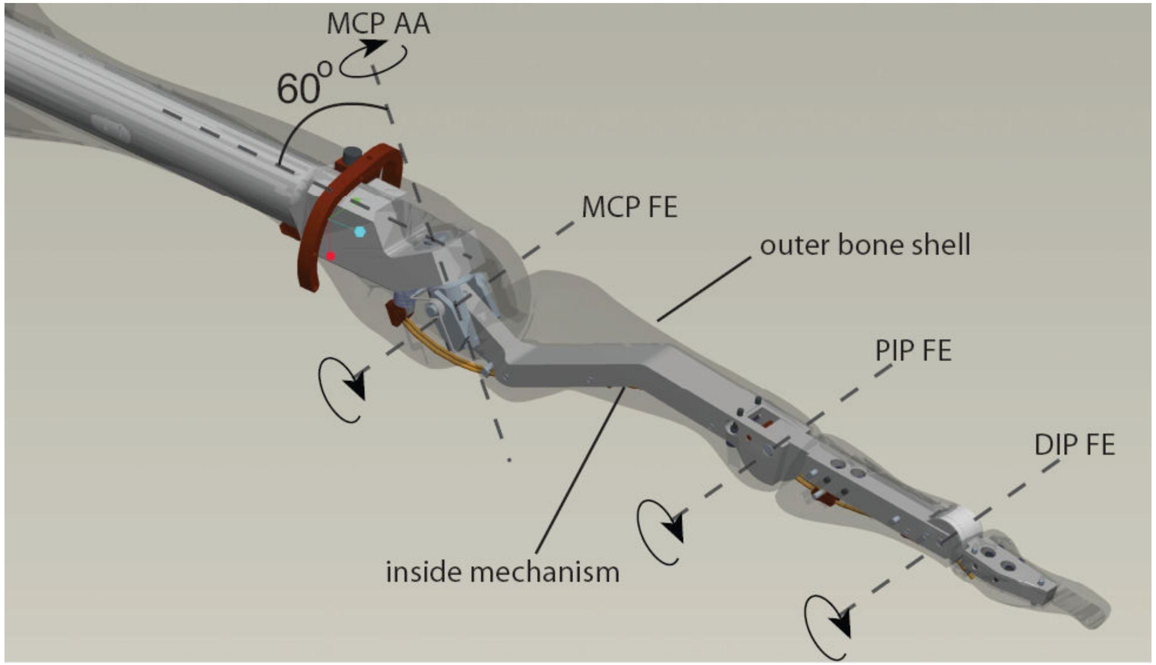
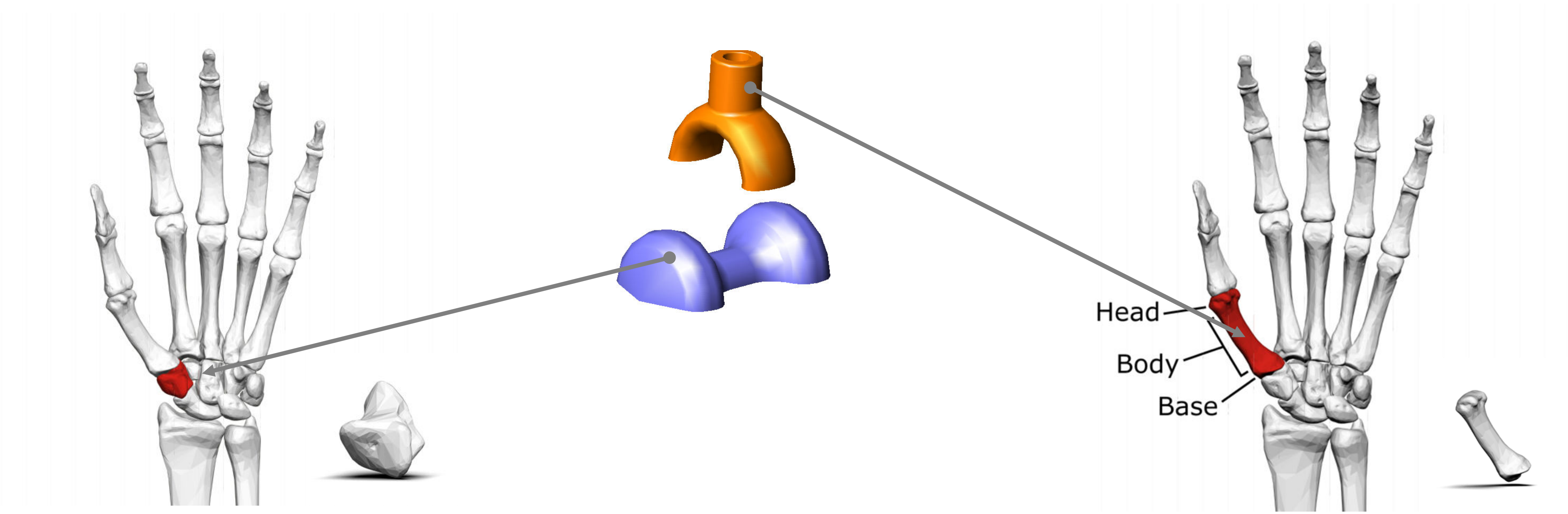
# The Conventional Mechanical Joint Used inside The ACT Hand




Typical mechanizing process

Introduction

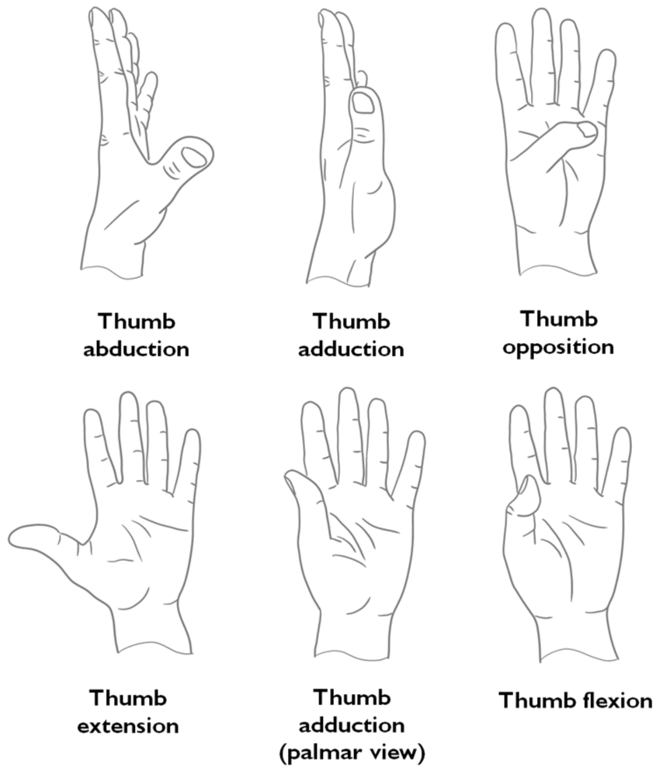
# The Common Mechanical Analogy of The CMC Joint

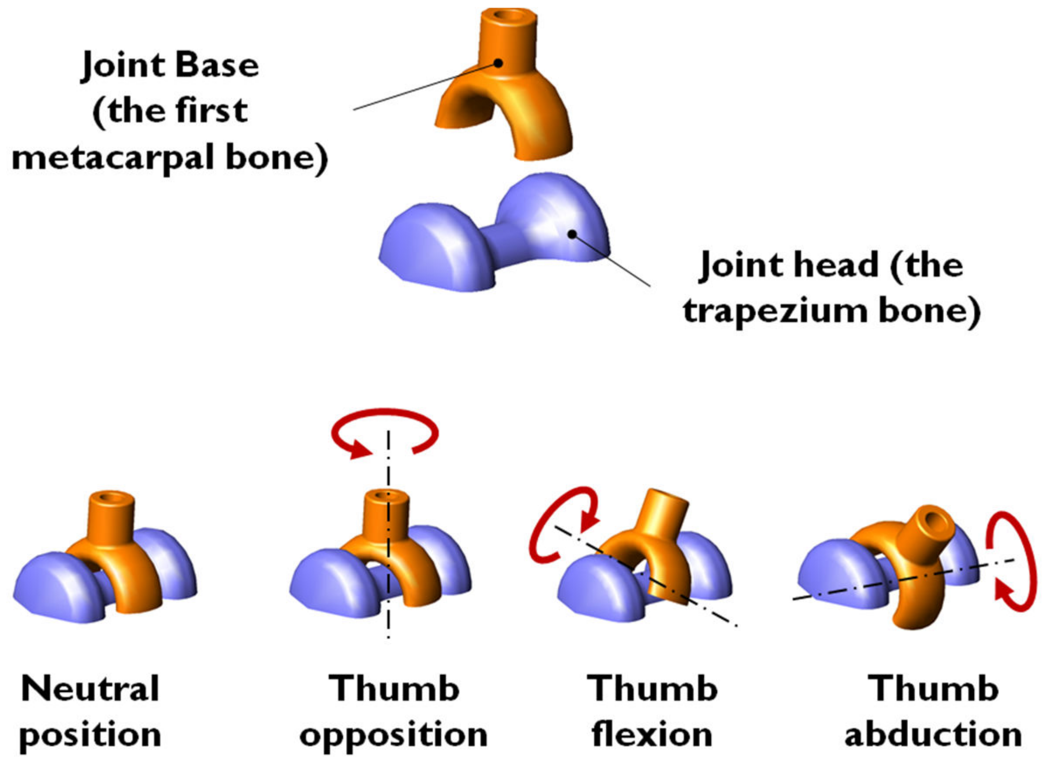



**The trapezium bone (cam)**

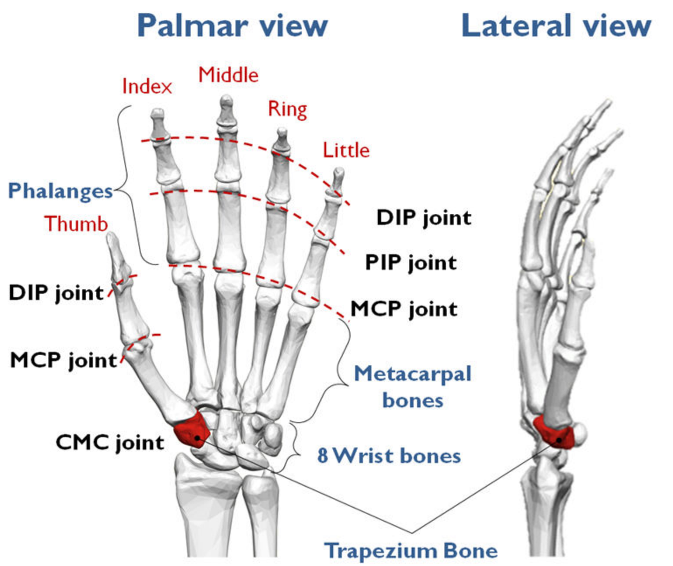
**The first metacarpal bone (follower)**

# The Common Mechanical Analogy of The CMC Joint

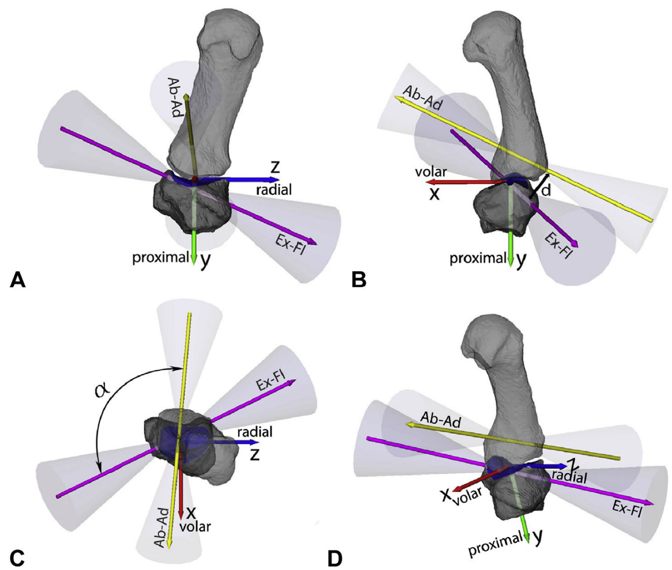


# The Shapes Of The Bones Decide The Basic Kinematics of The Human Hand



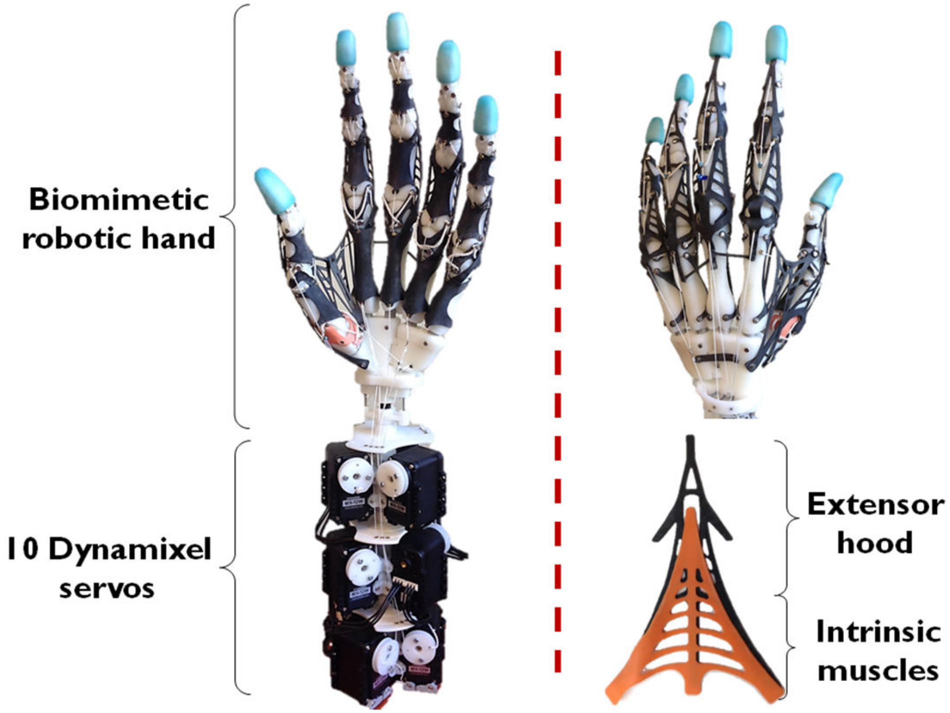

Trapezium bone of the human thumb




Unfixed joint axes(Crisco et al., 2015)

# Our Approach

Our highly biomimetic design truthfully matches kinematics of the human hand




(Xu and Todorov, 2016)

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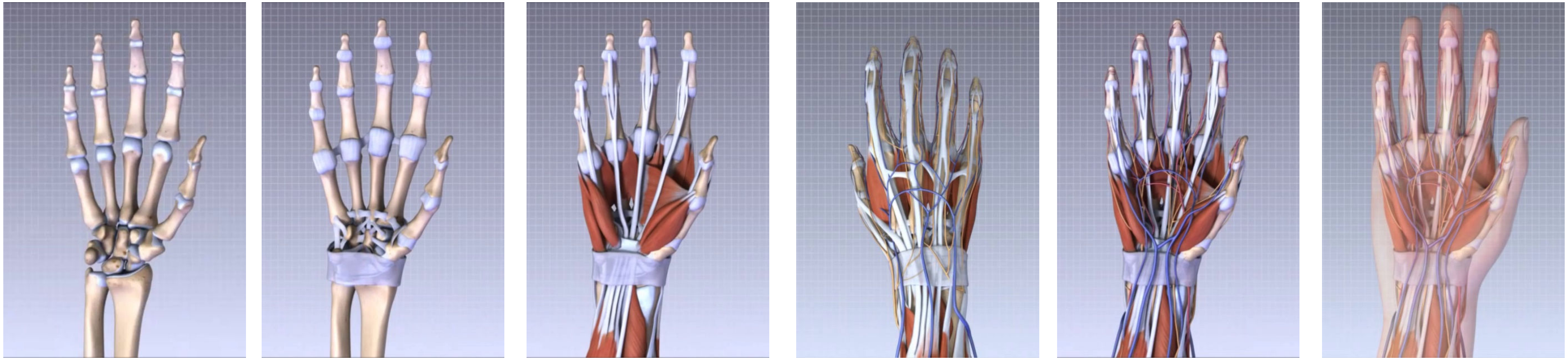
# Outline

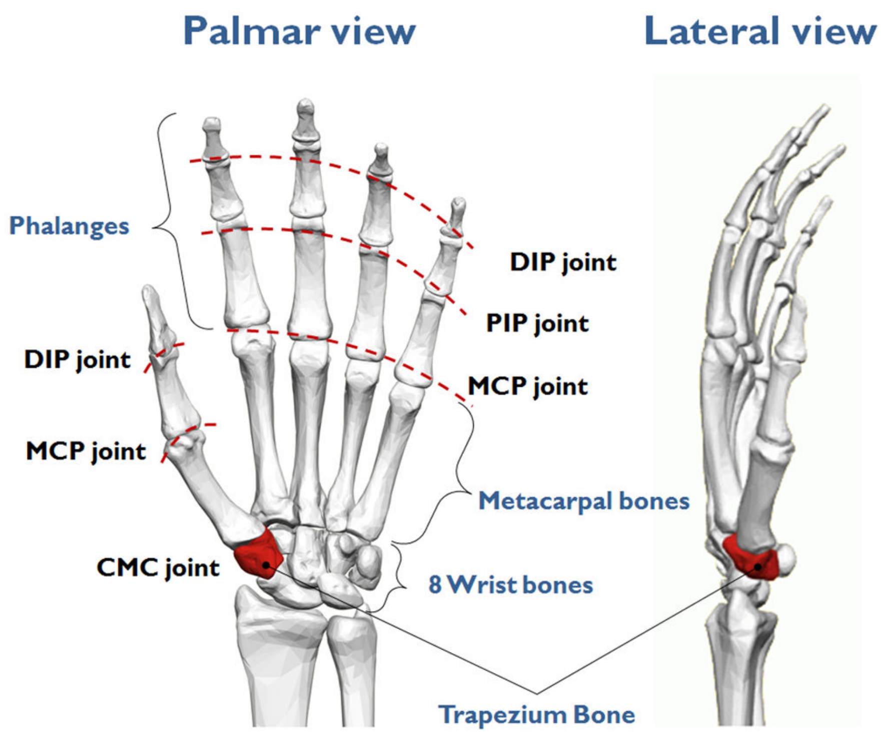
- **Introduction**
- **Important Hand Biomechanics**
- **Design & Prototype**
- **Perspective on Broader Impacts & Future Work**

# Human Hand Anatomy



**Bones** | **Ligaments** | Tendon and muscles | Blood vessel & nerves | Skin

# Bones




- Contains 27 bones with 8 small wrist bones
- Four fingers and one thumb
- The scaffold for the soft tissues
- Trapezium bone is crucial for thumb opposition

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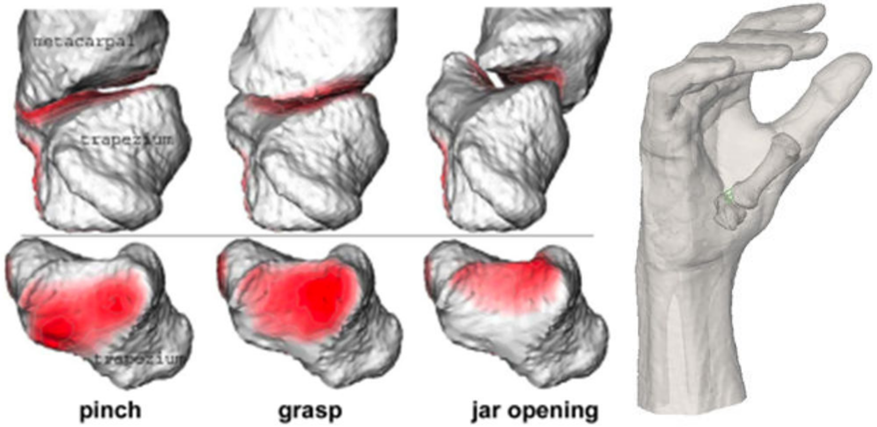
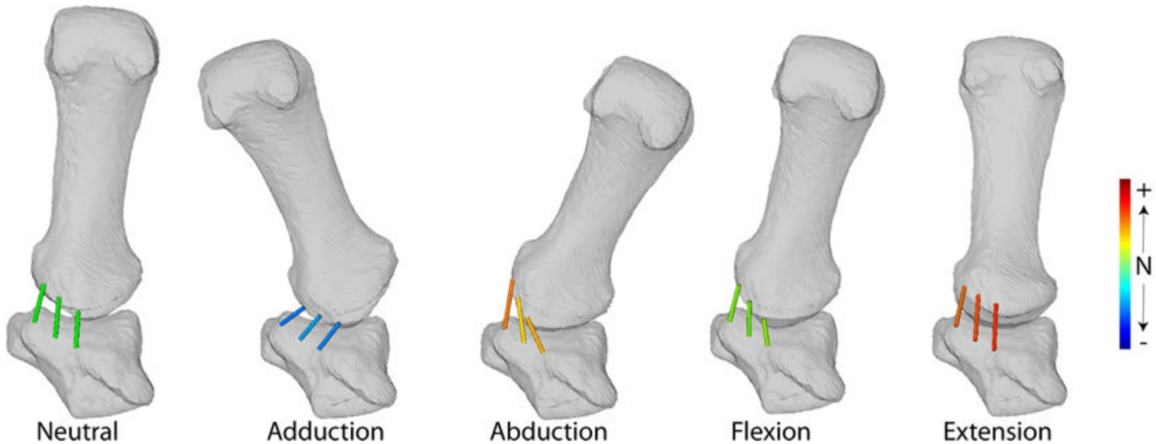
# Articular Surfaces Decides Basic Kinematics and Distributes Stress Better




Amy L. Ladd (2010)

Halilaj et al. (2013)

Important Hand Biomechanics

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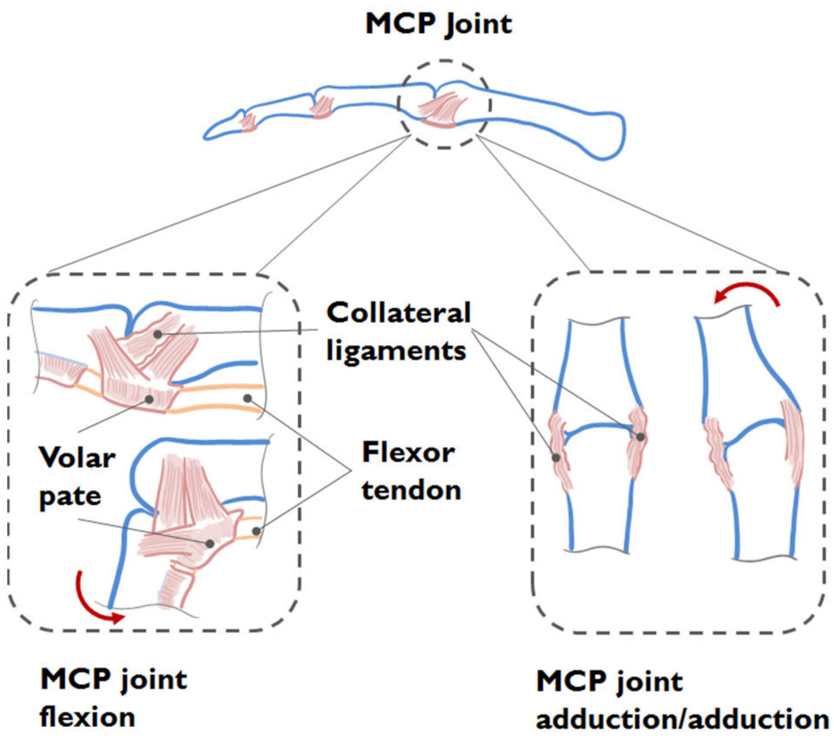
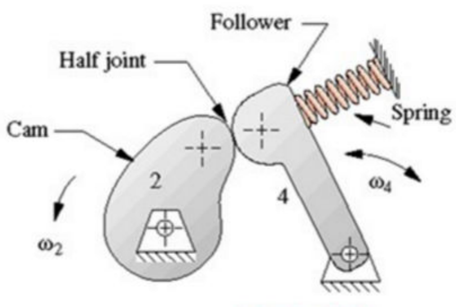
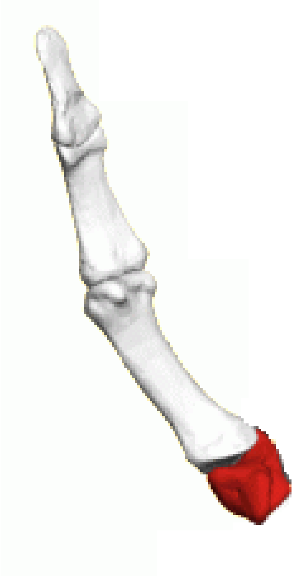
# Joint ligaments



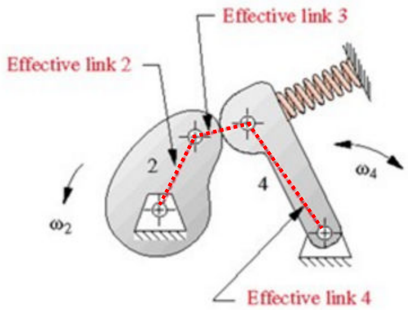

- The collateral joint ligaments – prevent abnormal sideways bending
- The volar plate -- prevents hyperextension
- Stabilize the finger joints by forming the joint capsule
- The joint capsule shapes the ROM of the finger

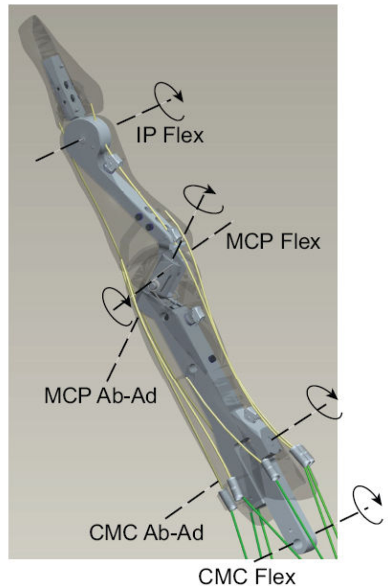
# Biological Joint Requires Less Parts



Human thumb
(Cam-follower CMC joint
with 2 parts)



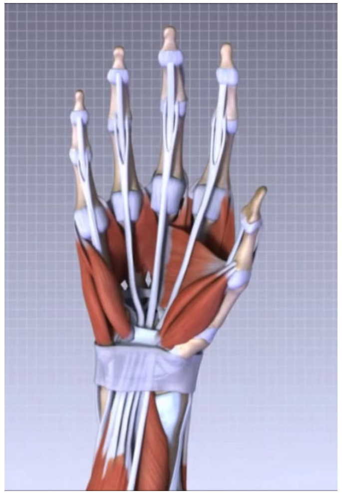

Thumb of the ACT Hand
(Linkage CMC Joint with 3 parts)

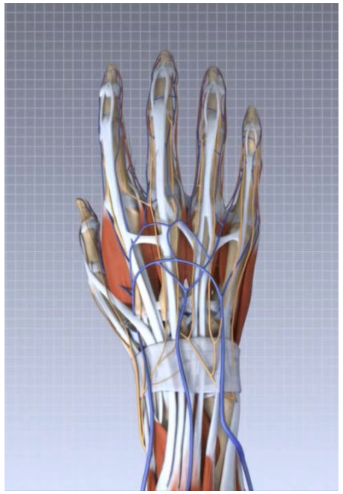
Norton, Robert L. "Design of machinery: an introduction to the synthesis and analysis of mechanisms and machines." (1992): 294.

# Human Hand Anatomy

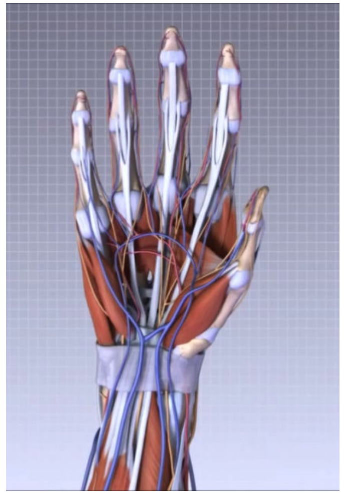
Bones

Ligaments

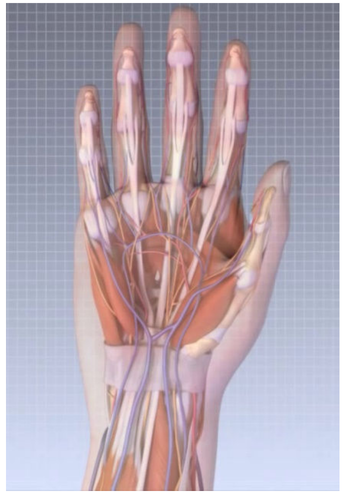




**Tendon and muscles**

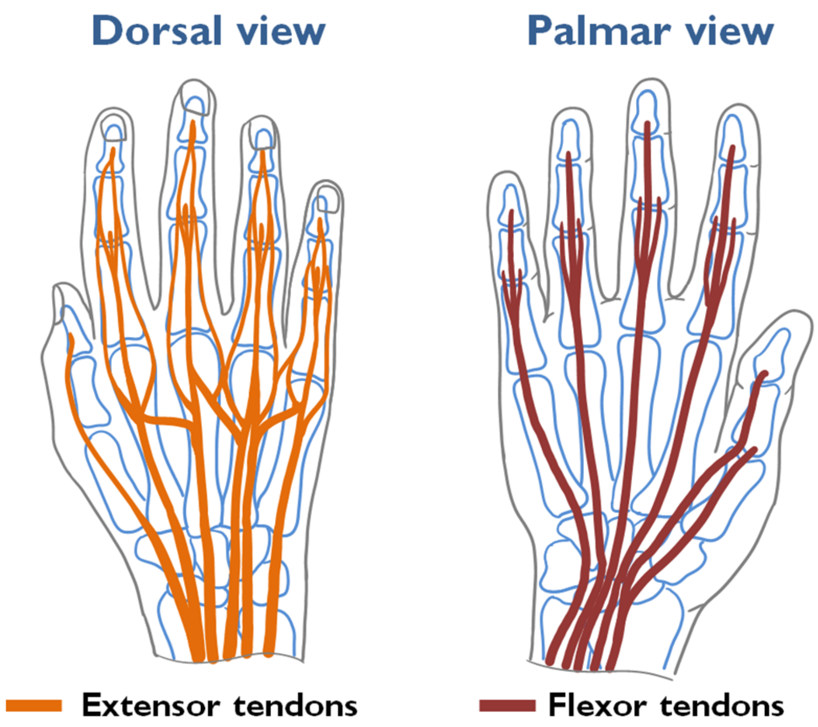


Blood vessel & nerves



Skin

# The Extensor & Flexor Tendons -- The Transmission System




- The transmission system of human hand
- Finger straightens – pull the extensor tendons
- Finger bends – pull the flexor tendons
- Contain built-in mechanical advantages.

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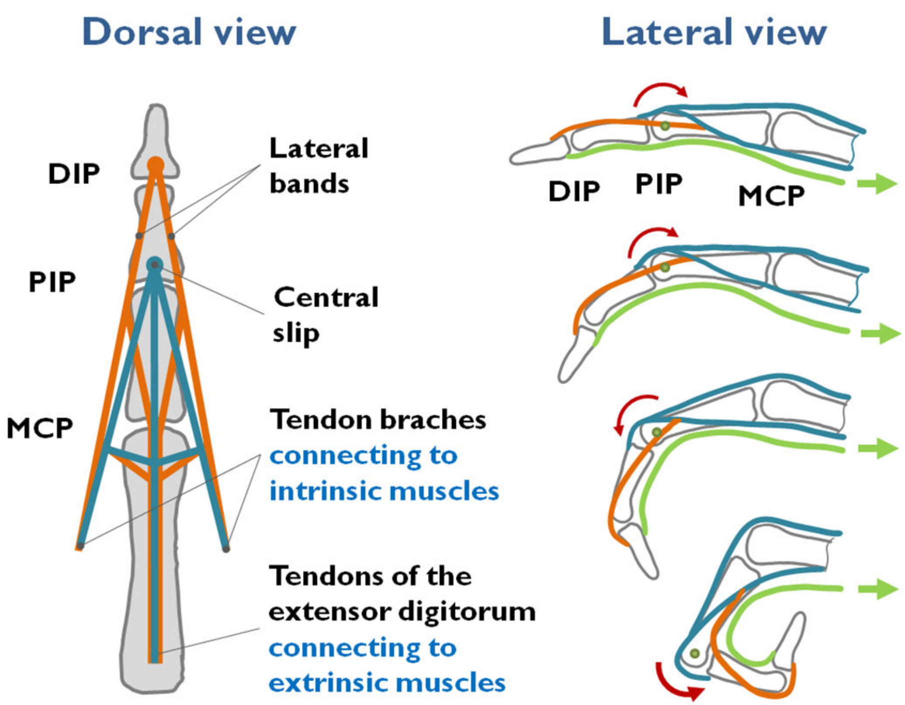
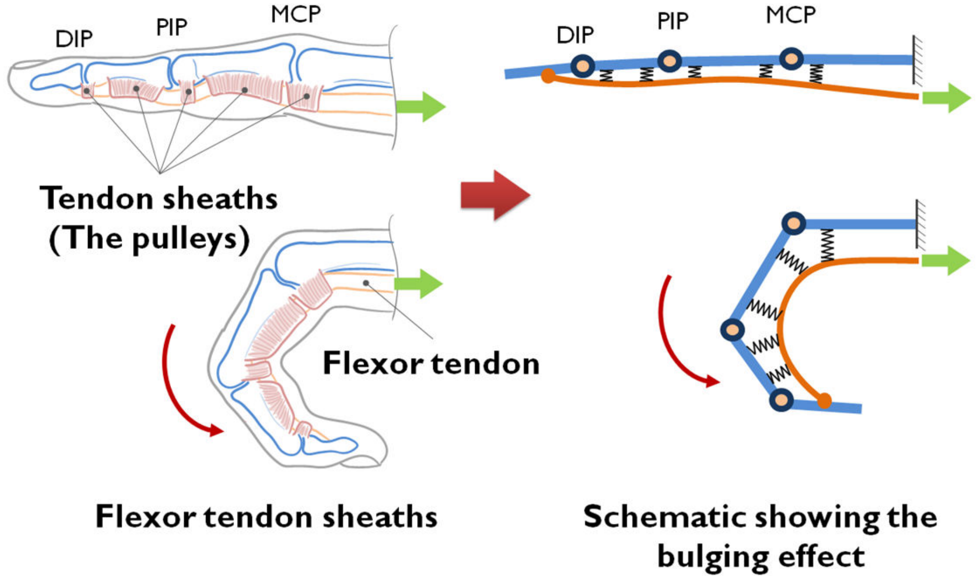
# The Gliding Mechanism of The Extensor Hood




- A thin web-structure
- Capable of changing shapes during different finger movements
- Smartly regulating joint torques during finger extension and flexion motions.

# The Bulging Process of The Tendon Sheaths




# Summary of The Important Hand Biomechanics

- **Biological finger joint**
  - **Bones**
    -- Demines the basic kinematics of finger movements
  - **Joint ligaments**
    -- Contributing to built-in compliance and shapes the ROM of each finger joint
- **Biomechanical transmission**
  - **Gliding mechanism of the extensor hood**
    -- regulating both extension and flexion torques at finger joints
  - **Bulging Tendon Sheaths**
    -- regulating flexion torques at finger joints

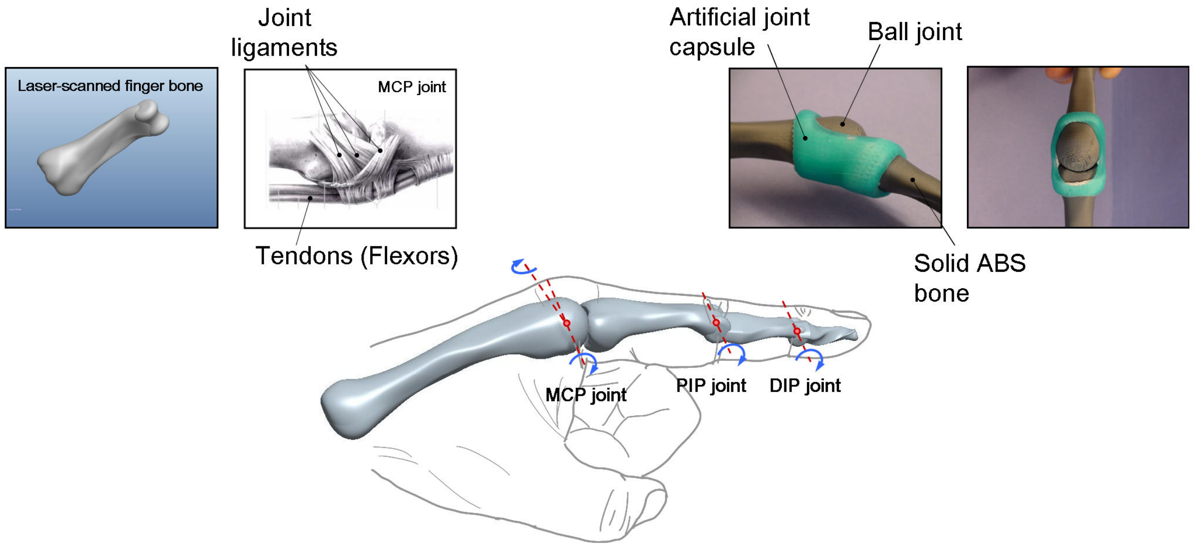
# Outline

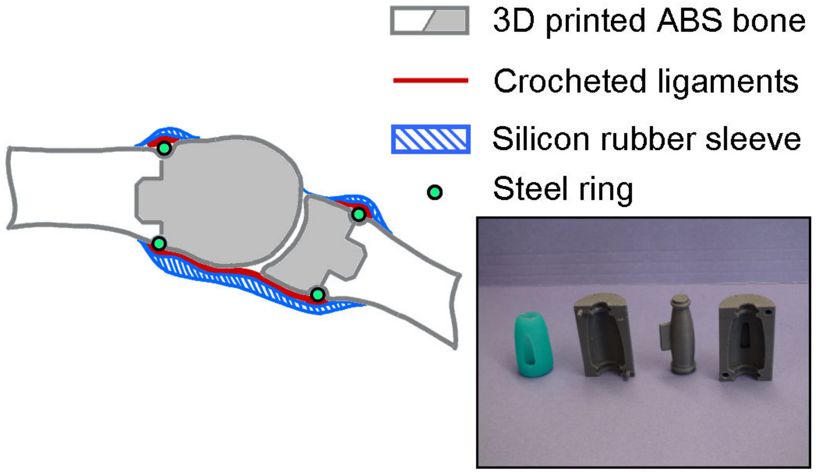
- Introduction
- Important Hand Biomechanics
- Design & Prototype
- Perspective on Broader Impacts & Future Work

# Design & Prototype

- **Artificial joint**
- **Biomimetic transmission**
- **Whole hand integration**

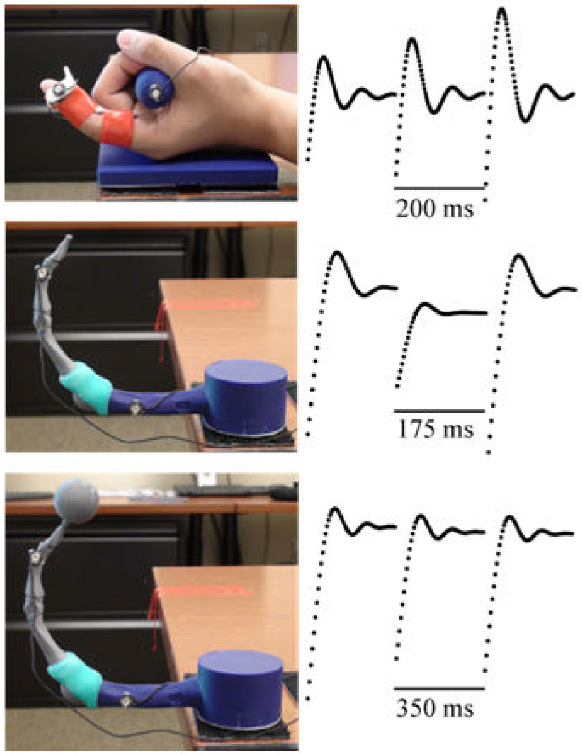
# Design And Prototyping Process of the Artificial Joint



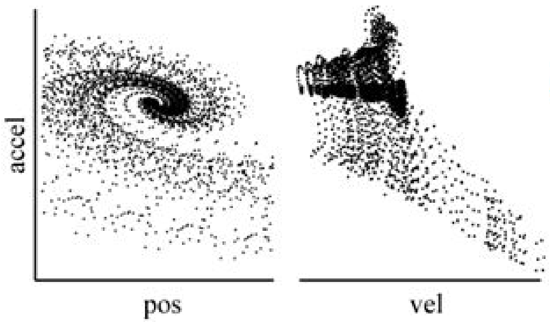

(Xu et. Al,, 2011)

# System Identification of The Artificial MCP Joint




- Two thicknesses of the silicon rubber sleeve:
  - Thin – 1.5 mm
  - Thick – 2.0 mm
- Effect of external weights:
  - Unloaded
  - Loaded – 7.5g mass
- 120 manual perturbations at ~1 Hz
  - 2 Human
  - 4 Artificial
- Motion capture system at 480 Hz using a 7-camera system

# Modeling of The Artificial MCP Joint




$$\ddot{\theta} = -k - b\dot{\theta} + a_0 + a_1\cos(\theta) + a_2\sin(\theta) + c_1\psi + c_2\theta^2 + c_3\dot{\theta}^2$$

Where $\psi(t) = \int \tanh(\dot{\theta}(\tau))d\tau$

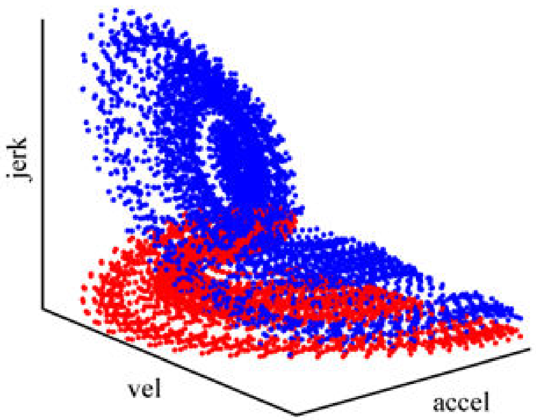



Table 4.3: Comparison of stiffness & damping for the human and artificial MCP joints

| *MCP joint of the index finger* | *Stiffness K (Nm/rad)* | *Damping B (Nms/rad)* |
|---|---|---|
| Human joint | 0.50 (averaged bewteen -0.2 to 1 radians) | 0.0142 (SD = 0.23) |
| Artificial joint | 0.534 +/- 0.025 (95% confidence interval) | 0.024 +/- 0.0003 ($R^2$ = 0.87) |

**Artificial Finger Joint**

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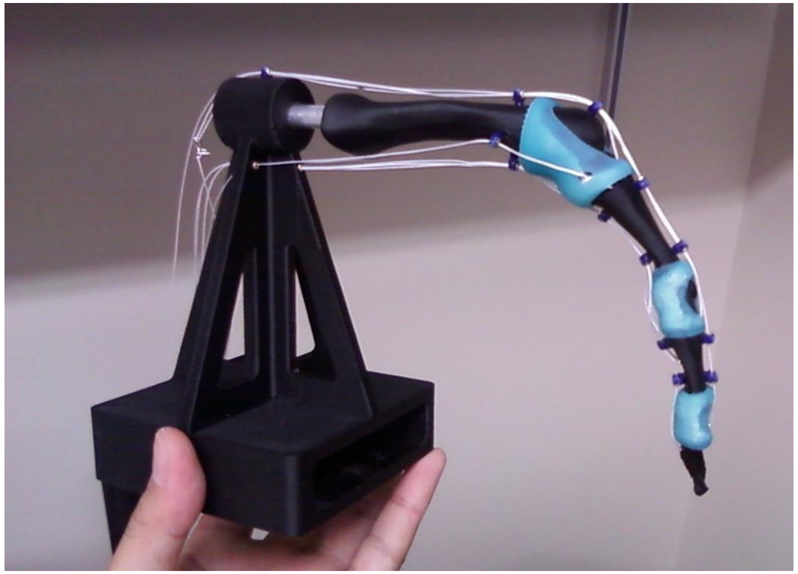
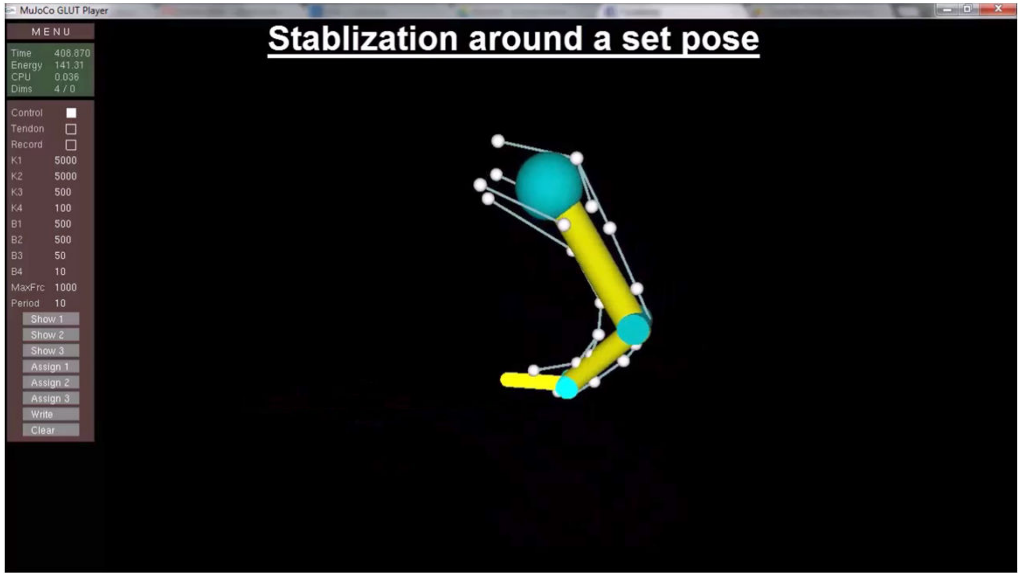
# Design of The Biomimetic Index Finger





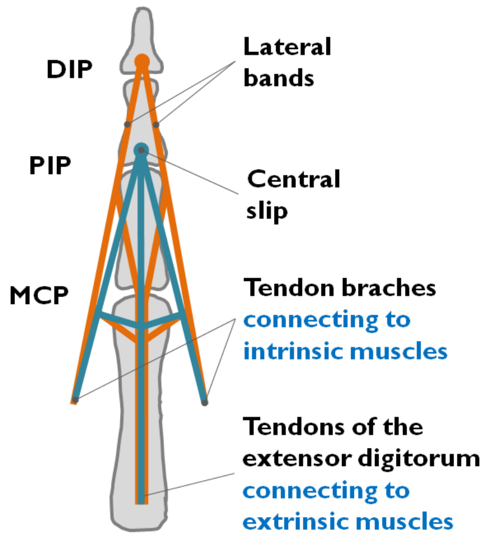

(Xu et. Al,, 2012)

## Artificial Finger Joint

# Design & Prototype

- **Artificial joint**
- **Biomimetic transmission**
- **Whole hand integration**

# Crocheted Extensor Mechanism




Henderson and Taimina, (2001)

- Compliant textile
- Withstand high tensile forces
- Can be made into any shape

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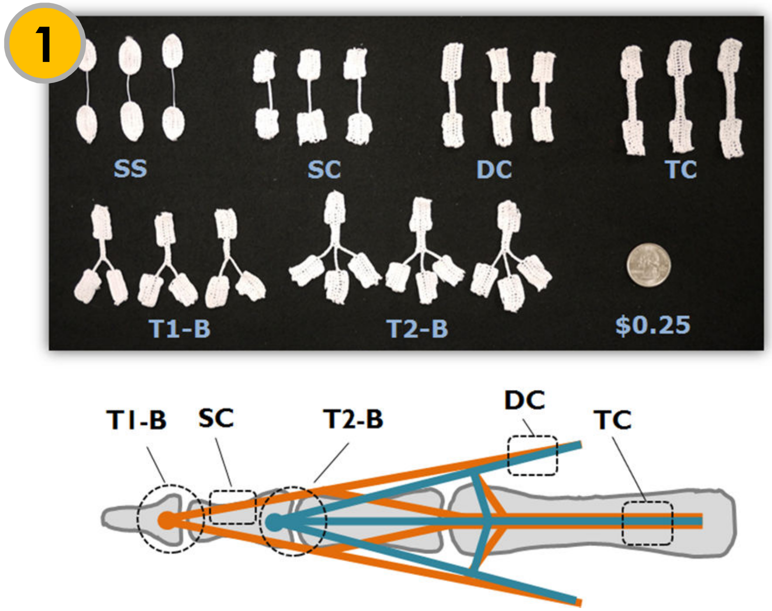
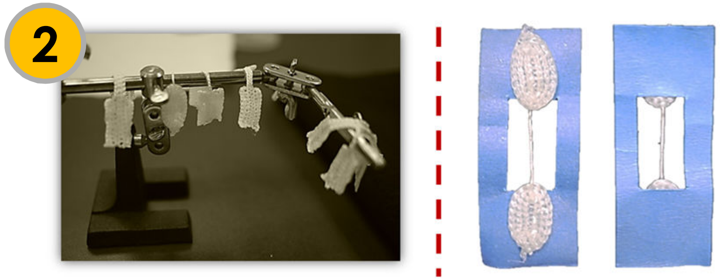
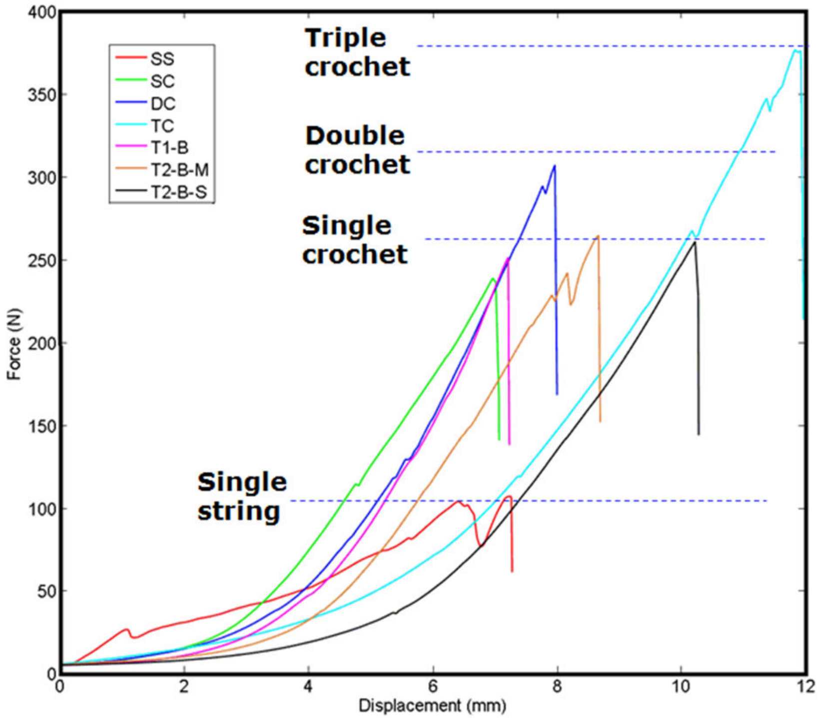
# Testing The Mechanical Properties of The Crocheted Extensor Mechanism




(Xu et. Al,, 2016)




# Results of The Tensile Test




- 15N/mm found in the human wrist extensor.

Table 3.1: Comparison of mechanical properties between different crocheted conditions.

| *Samples (n = number of the samples)* | *Ultimate load (N) Mean ± SD* | *Linear stiffness (N/mm)*[2] *Mean ± SD* |
|---|---|---|
| Single string (n=3) | 109.3 ± 4.2 | 17.6 ± 4.6 |
| Single crocheted chain (n=3) | 249.5 ± 9.5 | 57.7 ± 7.9 |
| Double crocheted chain (n=3) | 292.2 ± 14.8 | 62.3 ± 13.8 |
| Triple crocheted chain (n=3) | 440.7 ± 150.4 | 61.8 ± 20.1 |
| Type 1-branching (n=6) | 260.1 ± 20.0 | 59.2 ± 14.0 |
| Type 2-branching-middle (n =3) | 277.4 ± 22.2 | 60.5 ± 13.3 |
| Type 2-branching-side (n=6) | 277.6 ± 15.6 | 56.2 ± 10.6 |

[2]Linear stiffness values of the crocheted samples are calculated from the linear region of the curves.

(Xu et. Al,, 2016)

# The Crocheted Extensor Hood On The ACT Hand


Step 1.

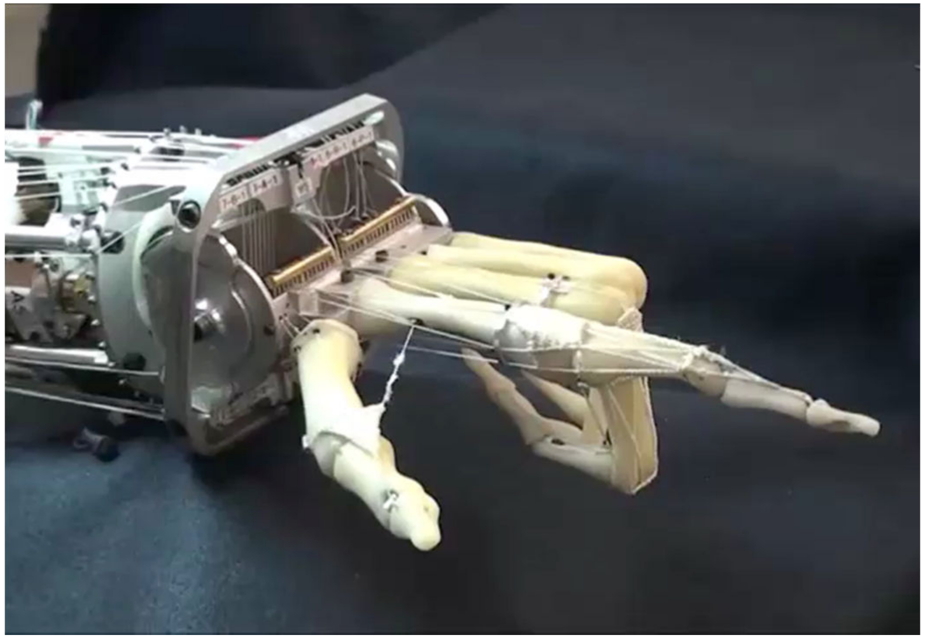

Step 2.


Step 3.


Step 4.


Step 5.


Step 6.



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# Improved Design of The Extensor Hood & Tendon Sheaths

Dorsal view

Palmar view

Biomimetic Transmission

# Design & Prototype

- **Artificial joint**
- **Biomimetic transmission**
- **Whole hand integration**

# Whole Hand Integration – Actuators

**3D-printed robotic hand (8-DOF)**

**10 Dynamixel servos**


(Xu and Todorov, 2015)

Table 7.1: The specifications of the Dynamixel servos.

| *Dynamixel Servo Model* | *AX-12A* | *MX-12W* |
|---|---|---|
| Working voltage (V) | 12 | 12 |
| No load speed (RPM) | 59 | 470 |
| Gear ratio | 254/1 | 32/1 |
| Resolution (°) | 0.29 | 0.088 |
| Range of Motion (°) | 300 | 360 |
| Communication Speed | 7343bps 1Mbps | 8000 bps - 4.5 Mbps |
| Weight (g) | 55 | 54.6 |
| Dimensions (mm) | 32 × 40 × 50 | 32 × 40 × 50 |

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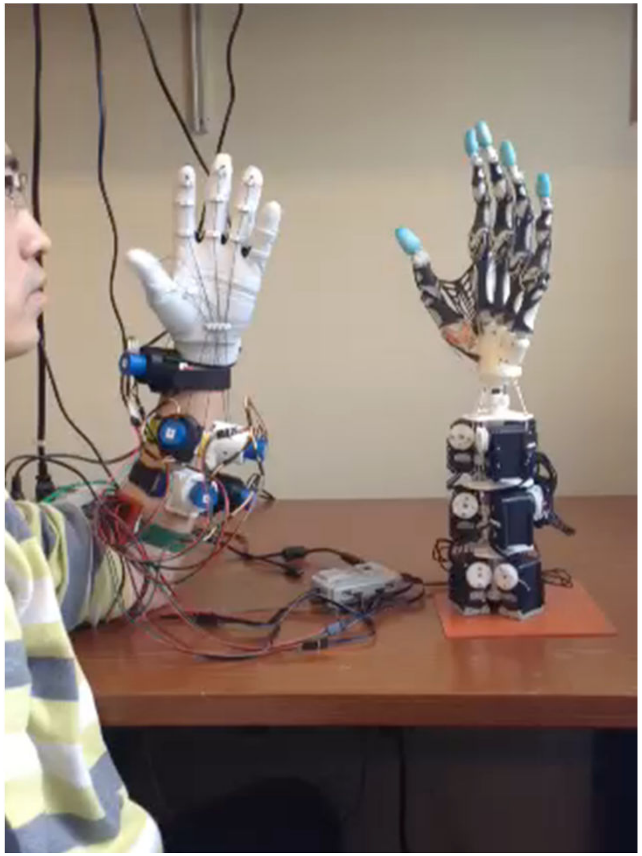
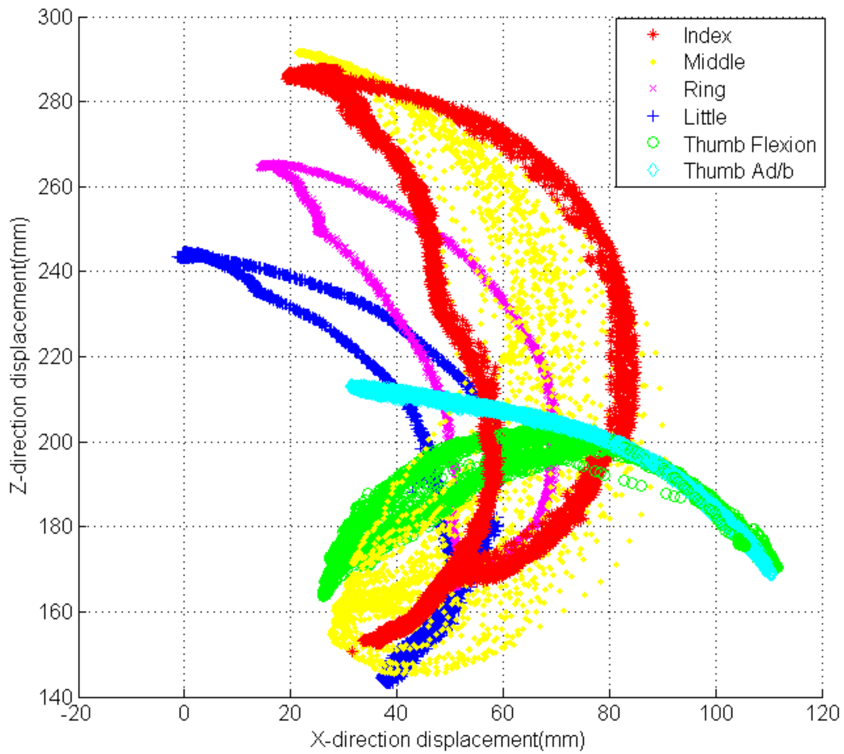
# Whole Hand Integration – Data Glove

The string potentiometer unit

# Evaluation




Index
Middle
Ring
Little
Thumb Flexion
Thumb Ad/b
Z-direction displacement(mm)
X-direction displacement(mm)
300
280
260
240
220
200
180
160
140
-20
0
20
40
60
80
100
120

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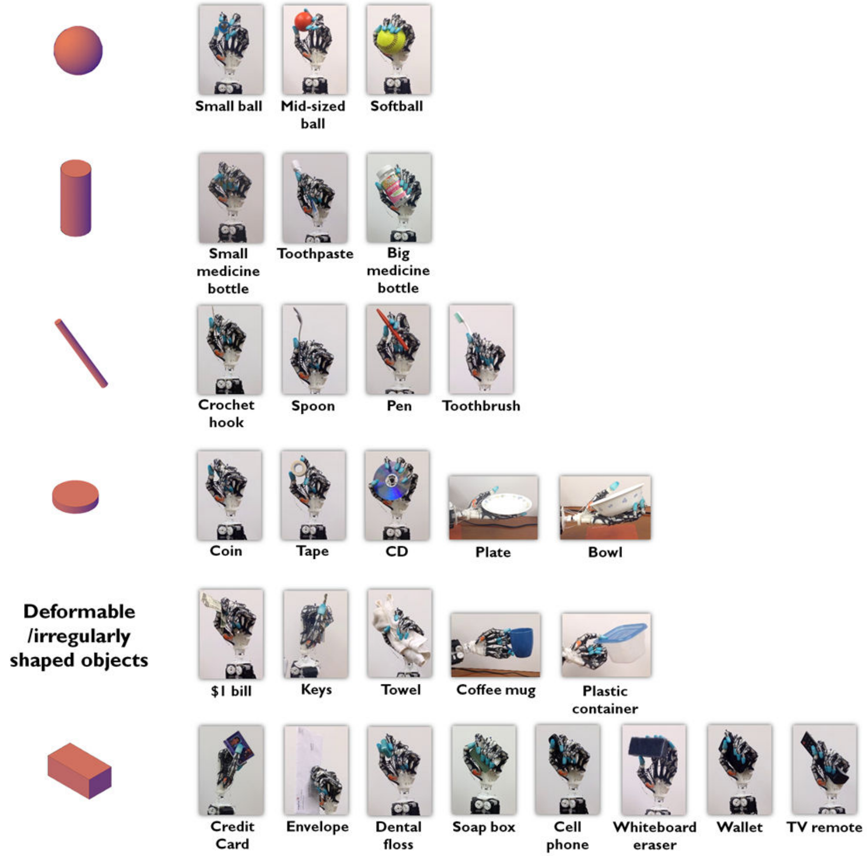
# Evaluation



# Outline

- Introduction
- Important Hand Biomechanics
- Design & Prototype
- Perspective on Broader Impacts & Future Work

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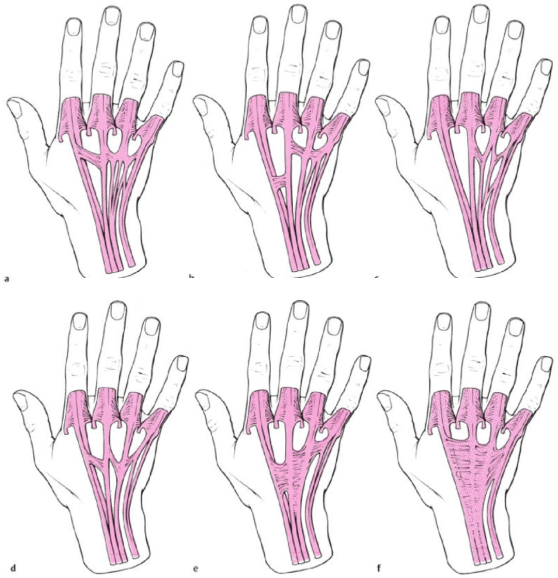
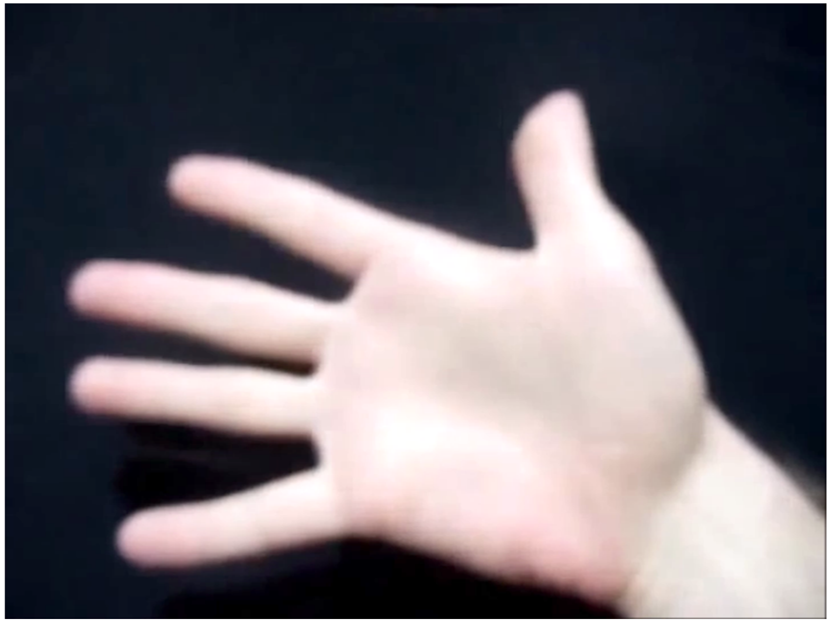
# Hand Dexterity Is A Personal Property





"Regardless of the degree of training, not all musicians are cable of the same finger movements" (Watson, 2006)

H.-M. Schmidt and U. Lanz, Surgical anatomy of the hand. Thieme. Stuttgart, 2004.

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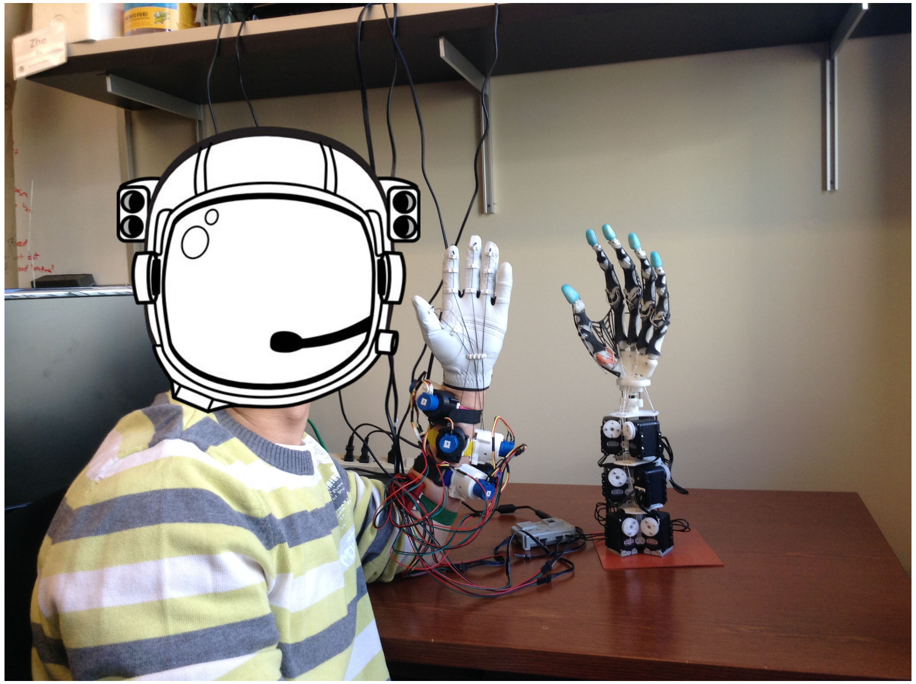
# Robotics -- Telemanipulation



Due to the one-to-one mapping of the kinematics, the telemanipulation process will also feature reduced cognitive load & easy programming.

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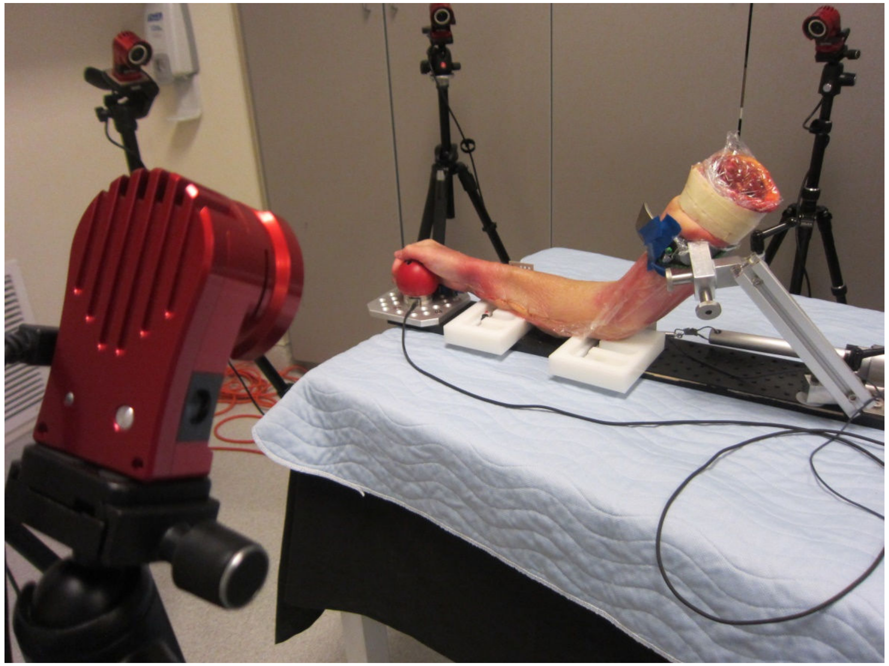
# Medical Research -- Scaffolds

Important biomechanical data can be physically preserved and then used to generate artificial scaffolds for limb regeneration research



RHCS lab, Oregon State University

Ott Laboratory, Massachusetts General Hospital / Harvard University

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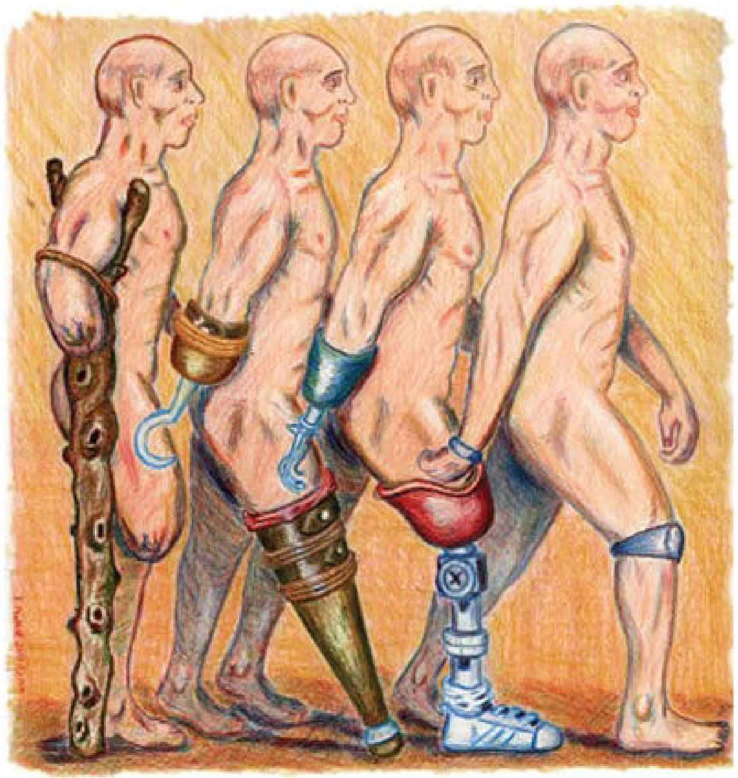
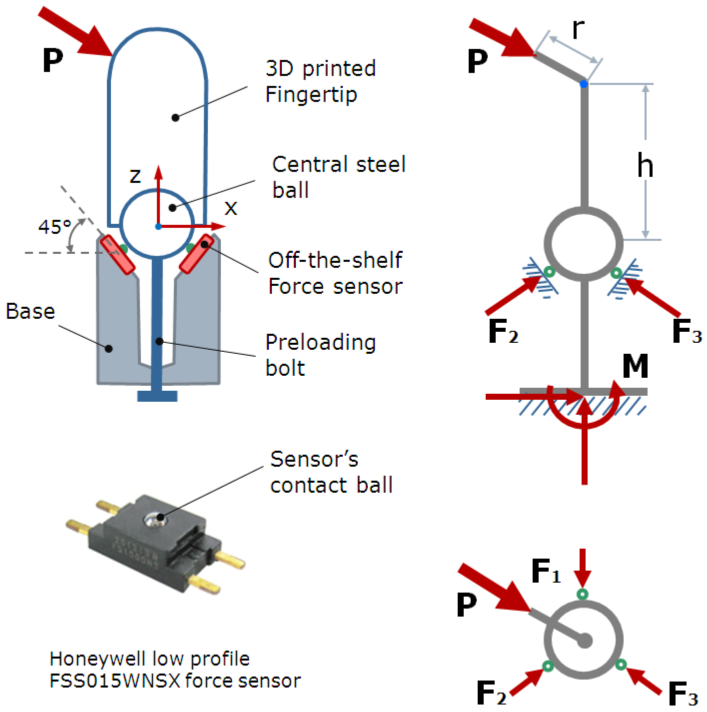
# Future – Artificial Limb



by Scott McNutt

# Future Work: 3-axis Fingertip Force Sensor




(Xu et al., 2014)