Toward Human-level Dexterity

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What is Neurobotics?

Goals: To assist, rehabilitate, and enhance human movements.

Methods

- Extract and understand neural signals.
- Use them to control robotic device. (closed loop)
Our Projects

Prosthetics
Brain-machine interface

Exoskeleton

Robotic Models

Neuron-Silicon Interface

Wearable Sensors

Sensory Transfer

Robotic Rehabilitation
Stroke
TBI

Animal Models

Photo: Garvens
Courtesy of Schwartz

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
Brain-controlled Robots: State of the Art

Andrew Schwartz et al.,
University of Pittsburgh, 2008
Human-level Dexterity

• What makes our hands dexterous?
• How can we make human-like brain-controlled robotic and prosthetic devices?

• Specific questions:
  – What neural and biomechanical structures makes our species unique?
  – Which features should be included in hardware?
  – How do humans utilize the neuro-control system for manipulation?
Evolution of Human Dexterity

Chimpanzee    Human
Young, J Anat., 2003.

Fat in the palm
Apical tufts
Strength moves towards thumb, index, and middle fingers. Fifth metacarpal becomes bigger.
Anatomically Correct Testbed (ACT) Robotic Hand*

- Replicates human hand’s joints, actuation, tendon structure, bone shapes.
- Details matter!
  - Bone shapes influence force capability.
  - Identify critical features and eliminate the rest.

Focus: Neural coding of movement

- What control choices humans have in manipulation tasks?
- How does neural coding change when learning new tasks?

Framework for Human Manipulation*

• Intricate anatomical features create redundant control system

  4 or 5 joints in thumb/finger
  6--8 actuators per finger
  Complex tendon web

  Several choices in muscle usage

How does the brain use the muscles in the hand?

Grasp

Posture + Force + Stiffness

Muscle forces

Electromyography provides biological data

Framework

Combine biological data with robotic models

* With Pedram Afshar
How the brain learns new tasks?¹

- Learning process trades off energy and error
  - Energy and error show exponential decay.

- Stiffness and error profiles
  - Stiffness increased rapidly, decreased slowly.
  - Error decayed rapidly and then flattened.

<table>
<thead>
<tr>
<th></th>
<th>Rise time</th>
<th>Decay time</th>
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<tbody>
<tr>
<td>Brief-contact</td>
<td>27</td>
<td>68</td>
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<tr>
<td>Full-path²</td>
<td>[1,6]</td>
<td>[10,17]</td>
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Error reduction prioritized over energy expenditure.

¹ Balasubramanian, Howe, Matsuoka, TBME 2008.
Error Reduction Prioritized Over Energy

- Learning slower in brief-contact tasks.
- Stiffness is increased rapidly to decrease error first.
- Application to computer gaming, pointer use, and precision assembly.
- Large physiological stresses can lead to injuries.
Summary

• Human-level dexterous manipulation
  – Manipulation is a redundant control task
  – ACT hand: vehicle for understanding biomechanical structures and neural coding in the human hand.
  – Task learning: Prioritization of error reduction over energy.

• Robotics can benefit from biological inspiration.

• Neurobotics provides insight into biological motor control.
Where it started

A fascination with the human control system. How can it do it all so reliably?

There will be a movie of finger percussion here
Applications

• Assist human-computer interaction

Cyberkinetics, Inc.
Muscle activation space

Is synergy maintained during transition?

Yes

No

What synergies are used during transition?

How fast is the transition?
Identify the data bits and the flow.
Evolution of the Human Hand

- A holistic view of manipulation:

What is human dexterity?

What are the enablers of human manipulation?

How do we use our hands?
History of Robotic Manipulation

Utah/MIT, 1983
Stanford/JPL, 1983
Barrett, 1993
Cog, 1995

Robonaut 1999
ShadowHand 2002
Gifu Hand III 2004
CyberHand 2006

But still robotic manipulation limited to pick-and-place operations.

Something unique about the human hand

Also, these robots do not help us understand directly the learning/control mechanism in the human hand.
Anatomically Correct Testbed Robotic Hand: Development*

• Four needs
  – Understand neural coding of human manipulation (Neuroscientists)
  – Passive and active hand biomechanics (Physiologists)
  – Hand reconstruction techniques (Surgeons)
  – Improve telemanipulators/prosthetics (Roboticists)

Affecting Society

- Improve mobility for seniors and disabled.
- Personal robotic assistants.
- Several outreach opportunities.
How about changing grasps?

- We change our grasps often.

- Two tasks: Same fingertip force, but different stiffness.

  - Task 1: Pick up half-filled glass
  - Task 2: Pick up full glass

  Task 1 changes to Task 2

Two transition strategies

![Muscle activation](image)

Maintain muscle synergy through transition

Change muscle synergy rapidly

Muscle activation

Muscle synergy

270 ms