Lecture 14: Prosthetics

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Stanford University
Updates

Office hours by appointment

Project:
• Sign up for meeting with teaching team on March 4
• Supporting data due on Friday, Mar. 1 at 4 pm
• Peer review form to be posted

Tour Friday
• Intuitive Surgical Mar. 1 (meet on campus at 1:15, arrive at 2:00)
  https://tinyurl.com/IntuitiveSurgicalTour
• Drivers, look for an email with your destination assignment
• Drivers taking other people will be reimbursed by mileage
Types of Prostheses
prostheses

artificial devices that replace injured or diseased body parts

Ocular prosthesis  Visual prosthesis  Artificial kidney

Also: Craniofacial (hemifacial, auricular, nasal, dental), neck (larynx substitutes, trachea and upper esophageal replacements), internal organs (bladder, stomach, heart), etc.
limb prostheses

purposes range from cosmesis to function
reasons for amputation

• Trauma
• Burns
• Peripheral Vascular Disease
• Malignant Tumors
• Neurologic Conditions
• Infections
• Congenital Deformities
limb prostheses

**Upper extremity:**
- forequarter
- shoulder disarticulation
- transhumeral prosthesis
- elbow disarticulation
- transradial prosthesis
- wrist disarticulation
- full hand
- partial hand
- finger
- partial finger

**Lower extremity:**
- hip disarticulation
- transfemoral prosthesis
- knee disarticulation
- transtibial prosthesis
- Syme's amputation (through ankle joint)
- foot
- partial foot
- toe
PROSTHETICS
LOWER EXTREMITY

BELOW KNEE
KNEE DISARTICULATION
ABOVE KNEE
HIP DISARTICULATION
Prosthesis Design and Control
components
types of prosthesis control

No control

Cable operated (body powered)

Myoelectric

Robotic
myoelectric prosthesis control:

- Electrodes pick up microvolts of electricity produced by contractions in the muscles of the residual limb.
- Signals are amplified and thereafter they activate the motor.
- In operating a hand there may be two electrodes, one on extensor muscles and one of flexor muscles groups, for opening and closing the hand.
robotic prosthesis control: peripheral invasive
robotic prosthesis control: targeted muscle reinnervation
Courtesy of The Rehabilitation Institute of Chicago and DEKA
(http://www.youtube.com/watch?v=ddInW6sm7JE)
robotic prosthesis control: targeted muscle reinnervation

• Provides an organized afferent pathway
  • Offers strong causal link between sensation and perception
  • Minimizes need for CNS plasticity
• Provides a natural afferent pathway
  • Near-normal thresholds for temperature, light touch, sharp/dull and pressure have been demonstrated
• Yet, there are many challenges and unknowns:
  • Density and types of mechanoreceptors in reinnervated skin unknown
  • No evidence of kinesthetic sensing
  • Relevance to proprioception unclear
  • Sensation of fingerpads has not been reported
  • Relationship to reinnervated muscle unclear
robotic prosthesis control: brain implant
robotic prosthesis control: brain implant

https://www.youtube.com/watch?v=ZuATvhIcUU4
discussion:

what are additional design challenges and potential solutions?
Human Sensorimotor Control Considerations
Comparison to Teleoperation

user — haptic device — teleoperated robot

motion and force signals
## Transradial Electric-Powered Prosthesis User Preferences

<table>
<thead>
<tr>
<th>Rank Order of Priority</th>
<th>Item Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fingers could bend</td>
</tr>
<tr>
<td>2</td>
<td>Thumb moved out to side</td>
</tr>
<tr>
<td>3</td>
<td>Required less visual attention to perform functions</td>
</tr>
<tr>
<td>4</td>
<td>Thumb could touch each finger individually</td>
</tr>
<tr>
<td>5</td>
<td>Could hold small objects better</td>
</tr>
<tr>
<td>6</td>
<td>Wrist rotated terminal device</td>
</tr>
<tr>
<td>7</td>
<td>Could hold large objects better</td>
</tr>
<tr>
<td>8</td>
<td>Could use it in vigorous activities</td>
</tr>
<tr>
<td>9</td>
<td>Wrist moved terminal device up and down</td>
</tr>
<tr>
<td>10</td>
<td>Middle joint of thumb could bend</td>
</tr>
</tbody>
</table>

Attention to perform functions was highly requested [1]. Users: the development of a system that “required less visual provided valuable insights on the priorities of arm-prosthesis fit patients. An extensive 1996 survey seek to seamlessly replace the user’s missing appendage, learn how to control it all over again. Upper-limb prosthesis be fitted with a powered prosthesis, and you would need to his own, through intense visual study.

Only one of those ever learned to walk or move on proprioception. A few individuals in the world have lost this complex interaction that we learn and perfect and employ the parts of your own body. Human motor control is a very proprioception - knowledge of the position and velocity of a such tasks unsighted. The sense you employ in such cases is objects are and then close your eyes, you can also perform and place it squarely on your head. If you know where such touch any object within arm’s reach. You can pick up a hat the motion of their upper limbs. You can easily reach out and user to bring the proxy to rest.

Our specific experimental setup and our failure to require the motions. We hypothesize that these slower speeds stem from improved success rate and ease of use but yielded slower all of these measures. Haptic position feedback significantly ease of use were all recorded. Visual position feedback increased of a target acquisition task, the proxy’s position was selectively behaves like a rotational damper. During successive repetitions to be a constant multiple of the applied torque, such that it of the right index finger; the proxy’s velocity was programmed targeted force-based motion as an analogy to prosthesis and teleoperator use. Thirteen subjects were asked to control the import ance of visual and haptic position feedback during force-based on human control of proxy movement.

I. INTRODUCTION

Katherine J. Kuchenbecker, Netta Gurari, and Allison M. Oka

Effect of Visual and Haptic Position Feedback

Abstract

— This research seeks to ascertain the relative value

Introduction

Healthy adult humans are amazingly adept at controlling

motor control, as the human body is designed to

maximize proprioception and contact. Both human

and robot control systems rely on proprioception and

contact. However, the user relies on these senses

when they use a prosthetic arm, while the robot

may rely on other modalities.

Section II provides

an overview of the different feedback modalities

available to human amputees. Section III describes

the development of a teleoperation system that

integrates feedback from the user’s limb. Section IV

presents the results of an experiment that compared

haptic and visual feedback.

II. LITERATURE REVIEW

A. Proprioception

Proprioception is defined as the sense of

position and movement of the body and its

parts. It is an important aspect of human

motor control, as it allows us to

perform tasks without conscious

motion. However, proprioception

in the upper limb is impaired in

amputees, as there is no direct

input from the muscles or

nerves.

B. Vision

Vision is another important

feedback modality that is

used by amputees. Vision

provides information about

the environment and

can be used to

predict the

position and

velocity of

objects.

C. Haptic Feedback

Haptic feedback is

important for

prosthesis

control.

Proprioception and contact

are the primary

modalities

used by

amputees

to

operate a

prosthetic arm.

D. Conclusion

This research seeks to

compare the relative value

of haptic and visual feedback

for amputee control of a

teleoperated arm.
role of vision and proprioception

Synergies

Decoupled

Hand Configuration

Mapping

Tactors

Principal Component Analysis

Grouped Finger Motions

Thumb-Only Motions
### A. Synergy Hand Motions

<table>
<thead>
<tr>
<th>Synergy 1 (Tactor 1)</th>
<th>Synergy 2 (Tactor 2)</th>
<th>Synergy 3 (Tactor 3)</th>
<th>Synergy 4 (Tactor 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S_{1,1}</td>
<td>S_{2,1}</td>
<td>S_{3,1}</td>
</tr>
<tr>
<td></td>
<td>S_{1,2}</td>
<td>S_{2,2}</td>
<td>S_{3,2}</td>
</tr>
<tr>
<td></td>
<td>S_{1,3}</td>
<td>S_{2,3}</td>
<td>S_{3,3}</td>
</tr>
</tbody>
</table>

### B. Decoupled Hand Motions

<table>
<thead>
<tr>
<th>Thumb Roll (Tactor 1)</th>
<th>Spread (Tactor 2)</th>
<th>Grasp (Tactor 3)</th>
<th>Thumb Flex (Tactor 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td></td>
<td></td>
<td></td>
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</table>
haptic feedback

- Normal force (e.g. “force reflecting” interface)
- Vibration (e.g., voicecoil)
- Local Shape (e.g. pin array)
- Shear (e.g., rotating wheel)
- Contact Location (e.g. moving roller)
- Thermal (e.g. Pelletier)

images courtesy Ed Colgate, Northwestern University
discussion:

what are additional sensorimotor control challenges and potential solutions?
future of prosthetics:

- Solving problems of cost, power, weight
- Direct human sensorimotor control
- Autonomy (or partial autonomy)
- Other ideas?