Challenges in UE Prosthetics

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LTI

Challenges in Upper Extremity Prosthetics

- Improving the mechanical patient interface
- Finding more sources of control information
- Getting better access to the control sources
- Duplicating all the motions of the intact human arm
- Reducing weight and compensating for gravity
- Finding better energy sources
- Using the same nerve/muscle signals that used to control functions to control them after amputation
- Cost effective manufacturing of better mechanisms

Goals

- Give transradial amputees full simultaneous control of three wrist functions and at least two hand functions
- Permit every transhumeral amputee to control internal-external rotation by rotating the humerus
- Use nerve-muscle grafts to give transhumeral amputees control of rotation of the humerus and elbow and all the hand/wrist functions listed above
- Give shoulder disarticulation amputees a functional shoulder joint as well as the controls listed above

Duplicating Motions of The Intact Joint

- Levels of availability
  1. No motion is available
  2. Friction constrains motion, but permits adjustment
  3. Manual lock /unlock is available
  4. Powered lock/unlock is available
  5. The motion itself is powered
- What is available now?
  - Hand
  - Wrist
  - Elbow/humeral rotation
  - Shoulder

Natural Control: Transradial

- Signals are accessed from all functional forearm muscles
- Requires implantable electrodes or signal analysis of surface myosignals
- New mechanisms are needed now to take advantage of these new control sources

Use Muscles to Acquire Nerve Signals

- Introduced by Todd Kuiken now at the Research Institute of Chicago
- Divide remaining large muscles into several bands
- Leave one band with original enervation
- Enervate remaining bands with severed nerves
- One patient has been successfully treated
- Implanted electrodes can improve this system
- This technique will enable transhumeral and SD amputees to control multiple functions naturally

Implantable Myosignal Transducers

- Powered by an RF source built into the external prosthesis
- System uses same power as 2 present “electrodes”
- Can transmit signals through sockets and sleeves
- Multiplexed so many muscles can be monitored
- Available by mid 2005

Compliance at the Elbow

- Cocontraction stiffens the intact joint
- Russell *et al* have shown that non-linear springs in the joint mechanism will permit more natural motion about this joint
- A new powered elbow will be needed
- Biceps and triceps myosignals are required full time to implement this scheme
  - This scheme is not usable without the Kuiken scheme for acquiring additional signals for control of hand and wrist functions

Autonomous Control

- Modern microprocessors have the capacity to make decisions based on sensor and user inputs
- The Bock Sensor Hand auto-adjusts its grip to accommodate changes in hand orientation
- Peter Kyberd’s research hands select an appropriate grip based on local force-sensor inputs

Hand-Wrist System for Eating

- Tilt sensors in the hand can direct wrist and elbow motors to keep spoons and cups properly oriented as food is brought to mouth
- All angles – elbow plus three wrist – require feedback to controller
- Can set a critical elbow angle where a further "Flexion" signal rotates cup to assist drinking
- Microprocessors can keep many modes of operation available for selection throughout day

Sound and Vibration for Feedback

- Dime-sized pager vibrators for feedback
  - Several fixed voltages can be used to produce multiple vibration rates in one vibrator
  - Controller usually needs an extra motor-control output
- Beepers require little control circuitry
- Miniature speakers can generate differing intensities and frequencies
- Sound is good during user training but annoying thereafter

Control Sources

- Relative motion of remaining body parts
  - Gross motion for cable operation of devices
  - Small motions that move transducers or tilt switches
  - Microcineplasty
- Surface myoelectric signals
- Signals from implanted myoelectric transducers
- Myoacoustic signals
- Pressure changes in sockets due to muscle contractions
- Direct acquisition of nerve signals
- Signals from brain implants

Force or Position Servo Control

- A force sensor can be placed in the harness or on the end of a cable
- Position is sensed by a linear transducer
- The joint controlled must have position feedback
- Servo control needs a “sleep” or set-it-and-forget-it circuit
- When the controlled device is “asleep,” a second device can be controlled by the same transducer
- LTI has a good position feedback kit for Bock hands

Skin-Surface Myoelectric Pickups

- Mount electrode-amplifiers in the socket
  - May have gain control on the back
  - May float to accommodate patient volume changes
- Mount separate metal electrodes in socket
  - Larger contacts can push further into soft tissue
  - Shielded cables are used to connect to amplifiers
  - LTI Cavity-Back™ electrodes eliminate connector bump
- Mount metal electrodes in a roll-on sleeve
  - Shielded cables are required
  - The sleeve must be washable
  - Snaps that attach cables are now too large

Acquiring the Myoelectric Signal

- Analog skin Electrode-Amplifiers have replaced threshold “electrodes”
- Metal electrodes and preamps are often separate
- Implantable myosignal acquisition is almost here

Research to Implement Kuiken Strategy

- This strategy attaches severed nerves to portions of muscles that are no longer functional to convert nerve signals into myosignals
- How does the neurosurgeon identify functional bundles in the nerves of the arm?
- Assuming implantable electrodes, how does the surgeon subdivide the muscle into new functional regions so that the myosignals are isolated?

Myoelectric Signal Processing

- Original threshold control—fixed speed
- Proportional control using amplitude variation
- Signal analysis to determine which muscle is acting followed by proportional control
  - Bernard Hudgins et al at UNB
  - Kristin Farry of Intelligenta, Inc.
  - Group at Northwestern
  - Group at Rutgers
  - Advanced Control Research Ltd.

Strategies for Shifting Control

- For controlling many devices with a few inputs
- One input controls two directions
  - Cookie crusher voluntary-open auto-close
  - UNB three-threshold fixed-speed
  - Alternate
  - Quick-Slow
- Two inputs and two outputs is trivial
- Two inputs to control two or more devices
  - Co-activate/co-contract to select second or third device
  - Quick contraction selects 1st device, slow contraction a 2^{nd} and cocontraction a 3^{rd}
- Use a simple switch or a dual-action switch for 3 devices

2-Input Speed-Control Strategies

- Subtract input 1 from input 2 to control speed
- First input crossing threshold takes control of direction and speed until signal drops below threshold
- Largest input controls speed and direction
  - This permits the rapid reversal of direction

Myoservo Control

- Joint angle is proportional myosignal strength
  - This is how the intact forearm is usually controlled by the biceps and brachialis muscles
- This control requires a well-filtered myosignal
- Both position and speed of an elbow can be controlled by just one myosignal

The EPP Approach to Control

- EPP is Extended Physiological Proprioception
  - A small motion of one body part controls powered motion around a prosthetic joint
  - The user receives force, position, and speed feedback
- A cable permits half EPP control of the elbow
- Both the Boston and VASI elbows have been operated this way
- Childress *et al* have done microcineplasties to achieve EPP

Alternate Control Inputs

- Force Sensing Resistors (FSR’s) can be activated by the acromion or by carpal remnants
- Linear transducers permit 1 to 3 cm of motion to generate one good control signal
  - Permits use of “wasted” body motions like shoulder protraction
  - May be placed in a harness or connected with a cable
  - Place in prosthesis and connect with a low-friction Bowden cable
- The dual-action switch is good for fixed-speed control
  - Harness and cable-pull versions are available
- Three and four position switches are difficult to control
  - Springs can make feeling extra positions easier
- Tilt switches are good for feedback and for patient control

Specs for the Multi-Input-Signal Hand

- Assume many signals from implanted electrodes
- Fingers have one or two P-P joints
- Fingers work together compliantly
- M-P axes are not parallel but have natural offsets
- Thumb is positionable
- Add all three wrist functions as part of hand spec
- Individual finger motion strong enough for typing
- Various sizes use interchangeable injection molded finger parts

Orienting the Hand

- Control all three wrist functions myoelectrically
- To save space use weak positioning motors
- Need a miniature electric bi-stable device to engage and disengage a double no-back clutch
- Back driving a weak motor can supply compliance with damping modulated by cocontraction of the appropriate agonist-antagonist pair
- For long limbs use thin tendon pullers around forearm or place some motors in hand

Feedback and Sense of Touch

- What simple feedback schemes would appeal to amputees now?
- Re-implanted and transplanted hands have been rejected when no sense of touch returned
- Use of force and pressure sensors to communicate with autonomous controllers must happen first
- Basic research is needed on communicating feedback information to severed nerves
- Can sensory feedback be provided at the same time that severed nerves are attached to “unused” muscles?

Energy Sources

- Energy source research depends on mass-market products
- Ni-Cd batteries are becoming obsolete, but can deliver the most current per unit of weight
- Ni-MH batteries have high capacity and current delivery
- Li-Ion batteries have the best energy storage per unit of weight. Special chargers are required.
- Methanol fuel cells will have much better energy per unit of weight
- Liquid CO2 is difficult to find but superior for powering many devices from one energy source

Mechanical Challenges

- Need for first speed and then force
  - Example: gear shift in Bock hand
  - Example: Childress' synergetic prehensor concept
- Use of a small motor to change position followed by a double no-back clutch to resist force
  - Example: need to lock humeral rotation while driving

Mechanisms Needed

- Manufacturable double no-back clutch
- Use of tendons to make compliant fingers etc.
  - Chris Lovecheck of NASA has some unique ideas for friction reduction of cross-joint tendons
- Thin less-than-1/2-inch diameter tendon pullers to place around forearm.
  - Each pulls 2 tendons alternately
- Revisit pneumatic actuators
  - Dick Plettenberg's dissertation

Harnesses

- Europe does not know about US harnesses and *visa versa*
- A workshop of five people from each side of the Atlantic could produce a useful report
- A photo report of the best harnessing techniques used in the US would help
- This would be a good project for the AAOP Upper Extremity Society

Improving Cable-Driven Arms

- Develop a cosmetically acceptable voluntary-close adult hand like the TRS child's hand
- Do a study to optimize efficiency of cable systems
  - What is the best type of Spectra™ cord for prosthetics?
  - When is a Teflon ™ -lined Bowden sheath better than a pulley?
- Introduce the Texas Assistive Devices multi-function wrist to the prosthetic community now
- Develop a simple way to change the spring constant of the conventional split hook
- Make locking an elbow easier for the user

Shoulder Joint Specs

- Easy for user to shift from locked to free swing in flexion/extension
- Abduction has sine-of-the-angle gravity compensation like Ergo Elbow
  - With a powered elbow, flexing the elbow will abduct the shoulder
- Joint must lock in abduction
- Both motions have both mechanical and electrical lock/unlocks available
- Powered abduction is available

New Mechanism for Elbow Disartic.

- Outside hinges have “linkage” cables to a parallel shaft in the forearm
- Parallel shaft is provided with the Bock Ergo-Elbow Spring-wrap lock/unlock mechanism

Partial Hand and WD Interfaces

- The Bock transcarpal hand makes these interfaces more important
- Need to maintain all three wrist motions of the transcarpal amputee
- Is there a good writeup on these interfaces or is additional R and D needed?

Improving Suspension in the OR

- The Marquard-Neff angulation osteotomy can retain humeral rotation and provide suspension
  - Georg Neff presented this at the last Orthopaedie Technic in Leipzig
- Christiansen *et al* in Norway report implanting a titanium T in the end of the humerus
  - What is the optimum shape for the ends of the T?
  - How should the implant be done in a young amputee?
- During amputation shorten the humerus by resecting 3.3” (85mm) while leaving the epicondyles

Lengthening of the Bones

- What are the criteria for lengthening the humerus or the radius and ulna?
- Should surgeons leave pendulous stumps if a lengthening will be possible after primary healing without infection?

Improved Sleeve Suspension

- Better coupling of roll-on sleeves to upper extremity prostheses
- Good way to pass myosignals through sleeves
- How much downward pull will the skin tolerate without developing stretch marks?
- Incorporate myoamplifiers into washable sleeves

Transradial Interfaces

- New socket design reported by John Migueles

Transhumeral Interface

- Large stabilizers prevent rotation
- Low medial brim allows full abduction
- Neoprene saddle aids suspension
- Saddle and straps are attached to centers of rotation in abduction
- Use of these centers isolates shoulder protraction and retraction from flexion and abduction
  - Separate linear transducers or switches can then be used in front and in back
  - A linear transducer in back permits servo control of the elbow while saving myosignals for hand control

Control of internal-external rotation

- Replace friction at the elbow turntable with an improved lock/unlock
- Offer an electric lock/unlock
- Offer electric low-power positioning with a double no-back clutch
- Implant a maxillofacial magnet in the end of the humerus to control internal-external rotation
  - Requires vector magnetic field sensor

Elbow Disarticulation Interface

- Epicondyles can provide partial suspension and full control of internal and external rotation
- What kind of socket is needed for T-shaped implant or for osteotomy?
- The available hinges are poorly suited to the job
  - They are too thick
  - Locks and lift springs add more thickness
  - A good four-bar-linkage design is needed (Ed Beiden)
- The Bock AFB mechanism compensates well for the weight of a hand

The Micro-Frame Shoulder Interface

- The Migueles design reported in JPO is good for myoelectric control but not for FSR control
- For FSR's the movable anatomy must be free to contact the FSR's
  - Suspension wings must be placed more medially
  - The best way to place the FSR's, on a bridge over the acromion, needs to be reported in JPO
- FSR's and switches permit more functions to be controlled independently
- More research is needed on the ideal shape for using both myoelectrodes and switches or linear transducers

Gloves and Cosmesis

- Three-jaw-chuck hands overstress silicone gloves
- No one has made a really dirt-proof vinyl glove
- No current glove material has the stretch properties of human skin
- Lack of stretch is particularly apparent when crossing the wrist, elbow, and other joints

Research Review Panels

- Put bright articulate users and prosthetists on panels that review research proposals

Improving Laminates

- Need for a quantitative study of laminates
- What layup gives the most stiffness in a frame?
- How much extra stiffness does a rib add?
- What is the best size and shape for a rib?
- Compare ”best” when cost is important with the optimal when cost is ignored
- Where do layups need to be stronger?

New Alloys Can Save Weight?

- Most parts still use WWII alloys
- 7075-T6 is much stronger
- Can we afford to use alloys stiffened and reinforced with boron and other exotic fibers?

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