Biosignals, Body-Machine Interfaces, and Exoskeletons

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History and Previous Work

2002,
BS(E) Biomedical Engineering,
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2002 - 2006,
Research Engineer
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2007,
MS(E) Medical Device and Diagnostic Engineering, University of Southern California

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Research Manager
Rehabilitation Institute of Chicago
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Our topics for today

- **Biosignals**
  - What are they, where do they come from, and what could we do with them?
- **<u>B</u>ody <u>M</u>achine <u>I</u>nterface / <u>B</u>rain <u>C</u>omputer <u>I</u>nterface**
  - What are they, what can they do, what are their pitfalls
- **Exoskeletons (my current work…)**
  - What is it, why do we want it, where is the state of the art now, and how can we control them

Learning Goals

- Know what a bio-signal is, and how to describe them
  - Know the most commonly used bio-signals for controlling machines human-machine interfaces
  - Know how to choose an appropriate biosignal, and procession methodology.
- What are body-machine / brain-computer interfaces, and how are they different from other bio-controlled applications.
- Be able to describe the similarities between exoskeletons and other human-robot interactions (teleoperation etc)

What is a biosignal?

A biosignal is a categorical term for all kinds of signals that can be measured, monitored, or recorded from living things – (not just signals we can use for control)

Don’t limit your thinking to only conventional signals!

How are biosignals classified?

Many different ways, depending on your goals

According to their **source or physical nature**, where the classification respects the basic physical characteristics of the considered process.

According to the **biomedical application**. The biomedical signal is acquired and processed with some diagnostic, monitoring, or other goal in mind.

According to **signal characteristics**. It is not relevant what is the source of the signal or to which biomedical system it belongs, when considering how to process the signal.

Where do biosignals come from?

<u>Anywhere</u> in the body

10 Broad classes of biosignals, based on how they are generated

1. Bioelectric
2. Biomechanical
3. Bioimpedance
4. Biomagnetic
5. Bioacoustic
6. Biochemical
7. Biooptical
8. Thermal
9. Radiological
10. Ultrasonic

Primary sources used for control signals

Biosignal Exercise (5 minutes!)

A biosignal is a categorical term for all kinds of signals that can be measured, monitored, or recorded from living things – (not just signals we can use for control)

So what kind of signals can you think of?

How would they be classified?
-Source
-Application
-Signal Characteristic

Bioelectric signals

They are generated by nerve cells and muscle cells. Its source is the membrane potential, which may be excited to generate an action potential. These individual potentials may be measured, but for control purposes, more gross measurements are used.

For example, when ***surface electrodes*** are used as sensors the electric field generated by the action of many cells which create a net field, that propogates through the tissue and can be measured on the surface.

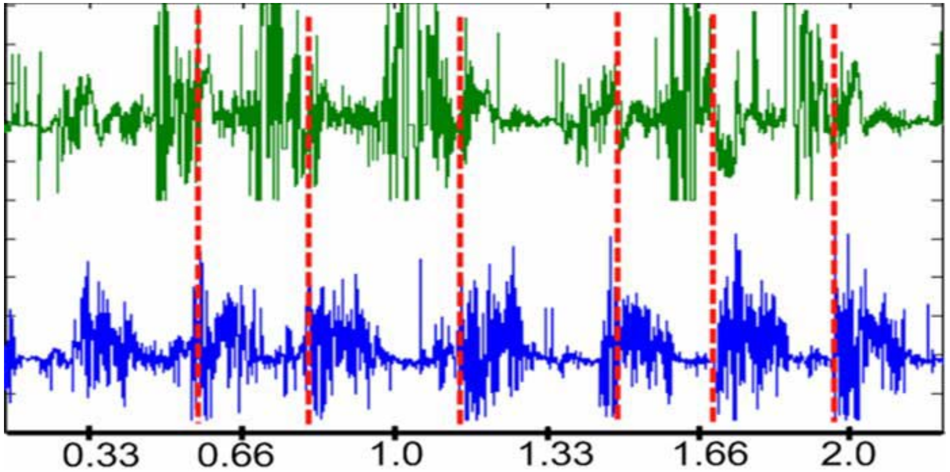
Bioelectric signals require a relatively simple transducer for their acquisition. A simple high-gain amplifier and a pair of metallic electrode tips can be enough to detect EMG.

Biomedical Signals

Classification	Acquisition	Frequency Range	Dynamic Range	Comments
Bioelectric				
Action potential	Microelectrodes	100 Hz–2 kHz	10 μV–100 mV	Invasive measurement of cell membrane potential
Electroneurogram (ENG)	Needle electrode	100 Hz–1 kHz	5 μV–10 mV	Potential of a nerve bundle
Electroretinogram (ERG)	Microelectrode	0.2–200 Hz	0.5 μV–1 mV	Evoked flash potential
Electro-oculogram (EOG)	Surface electrodes	dc–100 Hz	10 μV–5 mV	Steady-corneal-retinal potential
Electroencephalogram (EEG)				
Surface	Surface electrodes	0.5–100 Hz	2–100 μV	Multichannel (6–32) scalp potential
Delta range		0.5–4 Hz		Young children, deep sleep and pathologies
Theta range		4–8 Hz		Temporal and central areas during alert states
Alpha range		8–13 Hz		Awake, relaxed, closed eyes
Beta range		13–22 Hz		
Sleep spindles		6–15 Hz	50–100 μV	Bursts of about 0.2 to 0.6 s
K-complexes		12–14 Hz	100–200 μV	Bursts during moderate and deep sleep
Evoked potentials (EP)	Surface electrodes		0.1–20 μV	Response of brain potential to stimulus
Visual (VEP)		1–300 Hz	1–20 μV	Occipital lobe recordings, 200-ms duration
Somatosensory (SEP)		2 Hz–3 kHz		Sensory cortex
Auditory (AEP)		100 Hz–3 kHz	0.5–10 μV	Vertex recordings
Electrocorticogram	Needle electrodes	100 Hz–5 kHz		Recordings from exposed surface of brain
Electromyography (EMG)				
Single-fiber (SFEMG)	Needle electrode	500 Hz–10 kHz	1–10 μV	Action potentials from single muscle fiber
Motor unit action potential (MUAP)	Needle electrode	5 Hz–10 kHz	100 μV–2 mV	
Surface EMG (SEMG)	Surface electrodes			
Skeletal muscle		2–500 Hz	50 μV–5 mV	
Smooth muscle		0.01–1 Hz		
Electrocardiogram (ECG)	Surface electrodes	0.05–100 Hz	1–10 mV	
High-Frequency ECG	Surface electrodes	100 Hz–1 kHz	100 μV–2 mV	Notchs and slus waveforms superimposed on the ECG.

EMG

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles. An electromyograph detects the electrical potential generated by muscle cells activated. **EMG** is typically treated as an indicator of the amount of force in a muscle!



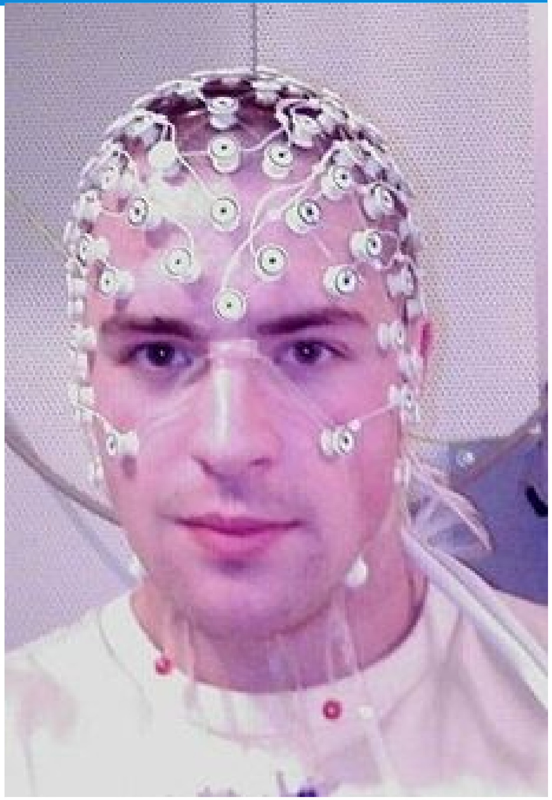
(Typical EMG during walking, Schorsch and Maas 2010)

(Bagnoli Desktop EMG System, Delsys)

EEG

Electroencephalography (EEG) is the recording of electrical activity along the scalp. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain.

(Typical EEG traces, Center for Health Psychology)



(EEG cap, Electrical Geodesics

Biomechanical signals

all signals that originate from some mechanical function of the biologic system.

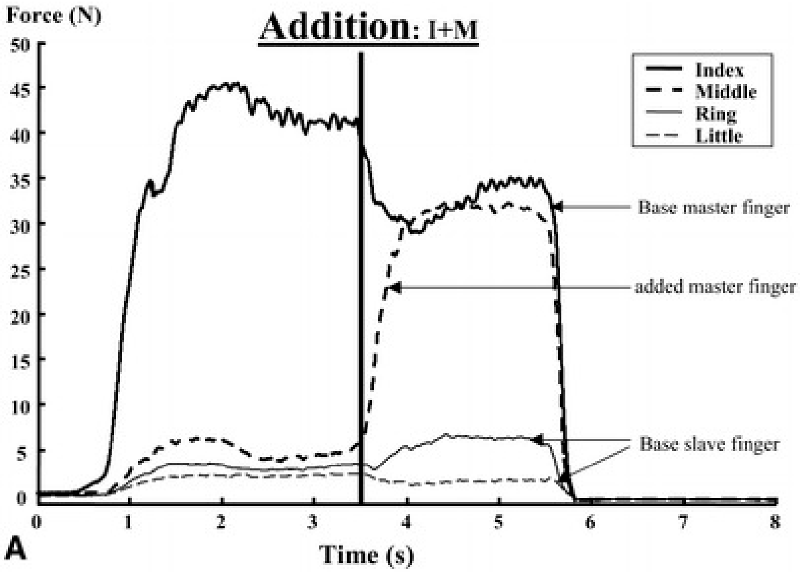
These signals include motion and displacement signals, pressure and tension and flow signals, and others.

You can use many different transducers, which aren't always simple and inexpensive.

Force Measurement

Force Cells are used to determine the endpoint force for a given joint. **Force Cells** can only detect the net force being applied, they can give no idea of the internal workings of the human body!

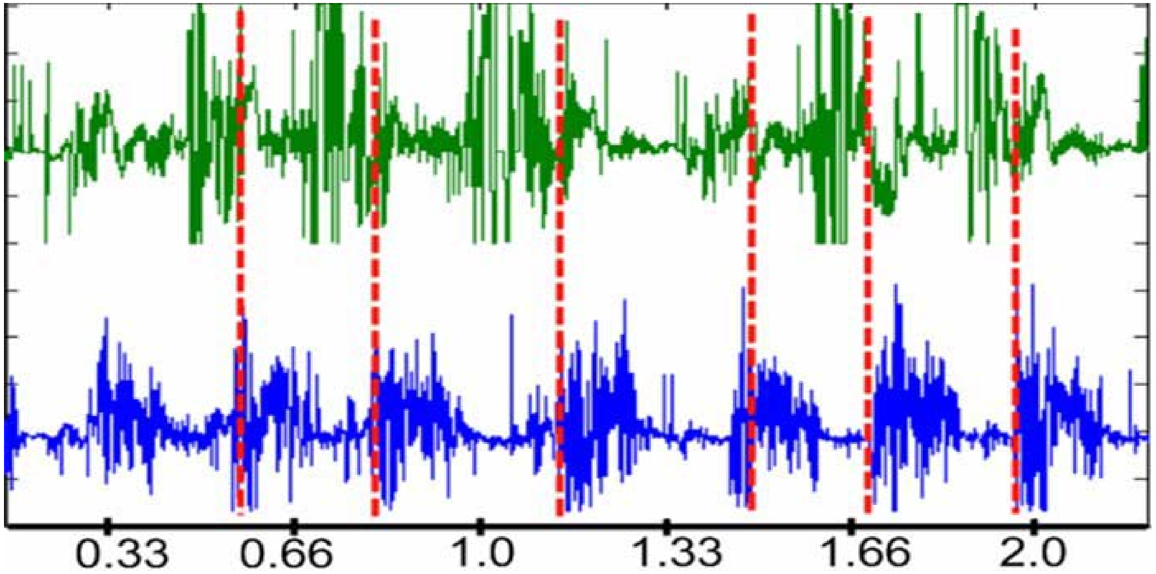
(In-line force sensor, Mega Electronics)



(Typical force traces, Sheng et al, 2003)

Noisy and imprecise

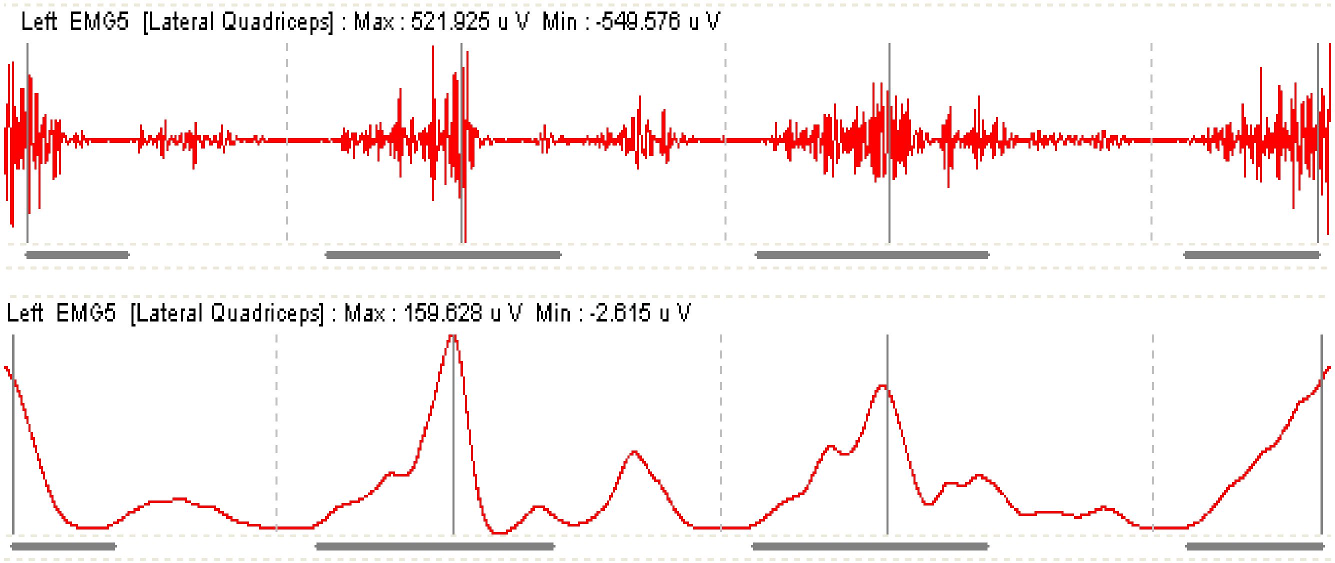
Biosignals are often only an estimate, and are often very noisy as well!



(Typical EMG during walking, Schorsch and Maas 2010)

Simplify

We filter and process the control signals that we detect, develop complex control methods, or reduce our output states!



(Typical EMG traces, Motion Lab Systems)

Biosignals summary

1. Come from many physiological sources
2. Biomechanical and Bioelectric are the most commonly used, from a control engineering standpoint
3. Are almost always non-stationary, and may be stochastic
4. Are often very noisy
5. Are often only an estimate of the real signal we want to measure

Body Machine Interfaces

Body Machine Interfaces (BMIs) or Brain Computer Interfaces (BCIs) are techniques and technologies for determining the intent of a human.

These systems are <u>currently</u> used for therapeutic and rehabilitative systems.

- Prosthetics,
- ‘Brain controlled’ wheelchairs
- Walkers to help the paralyzed

What signals?

Usually, BMIs try to take signals as close to the point of action as possible.

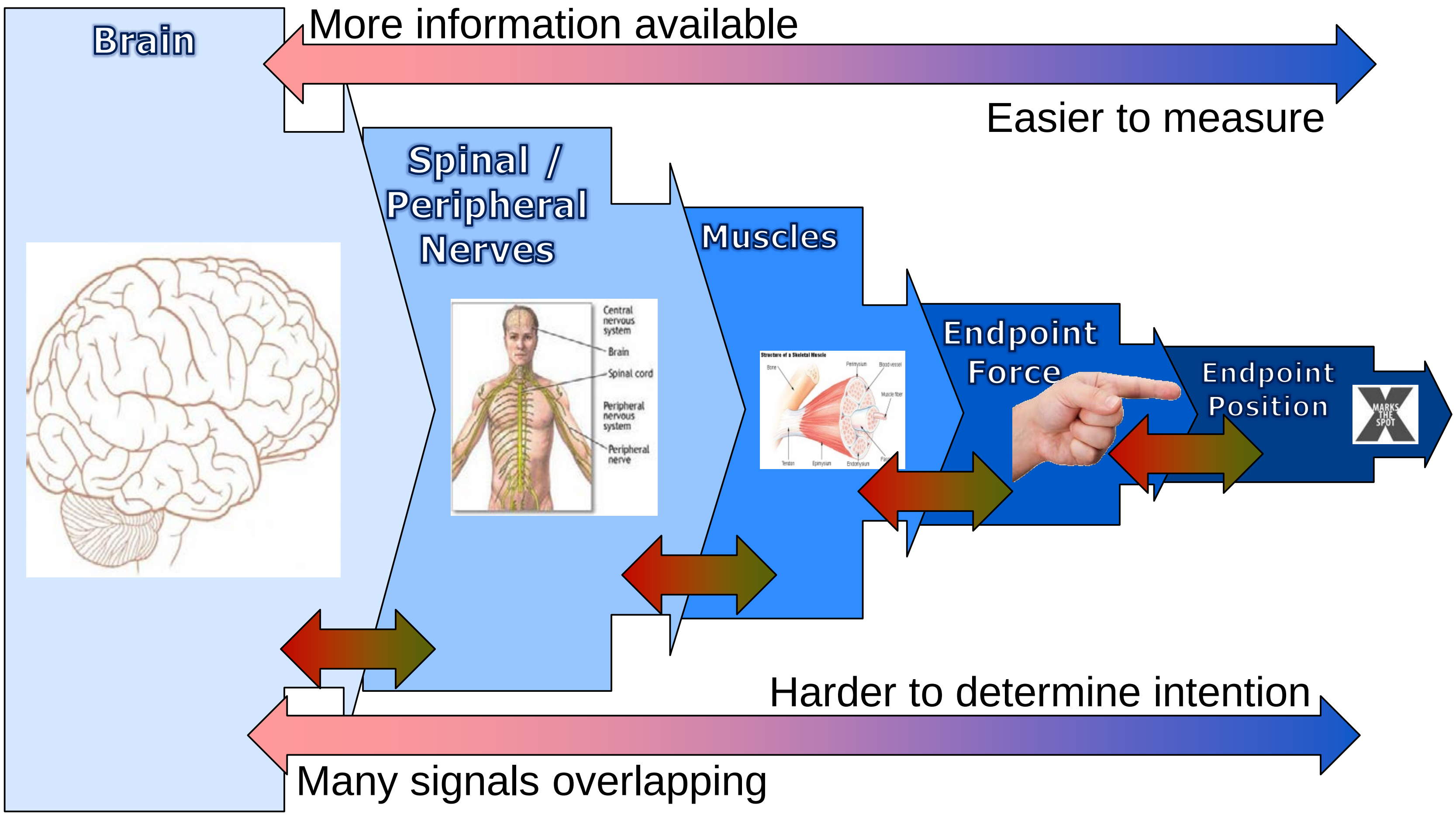
Force->EMG->Peripheral Nerves->EEG

Why?

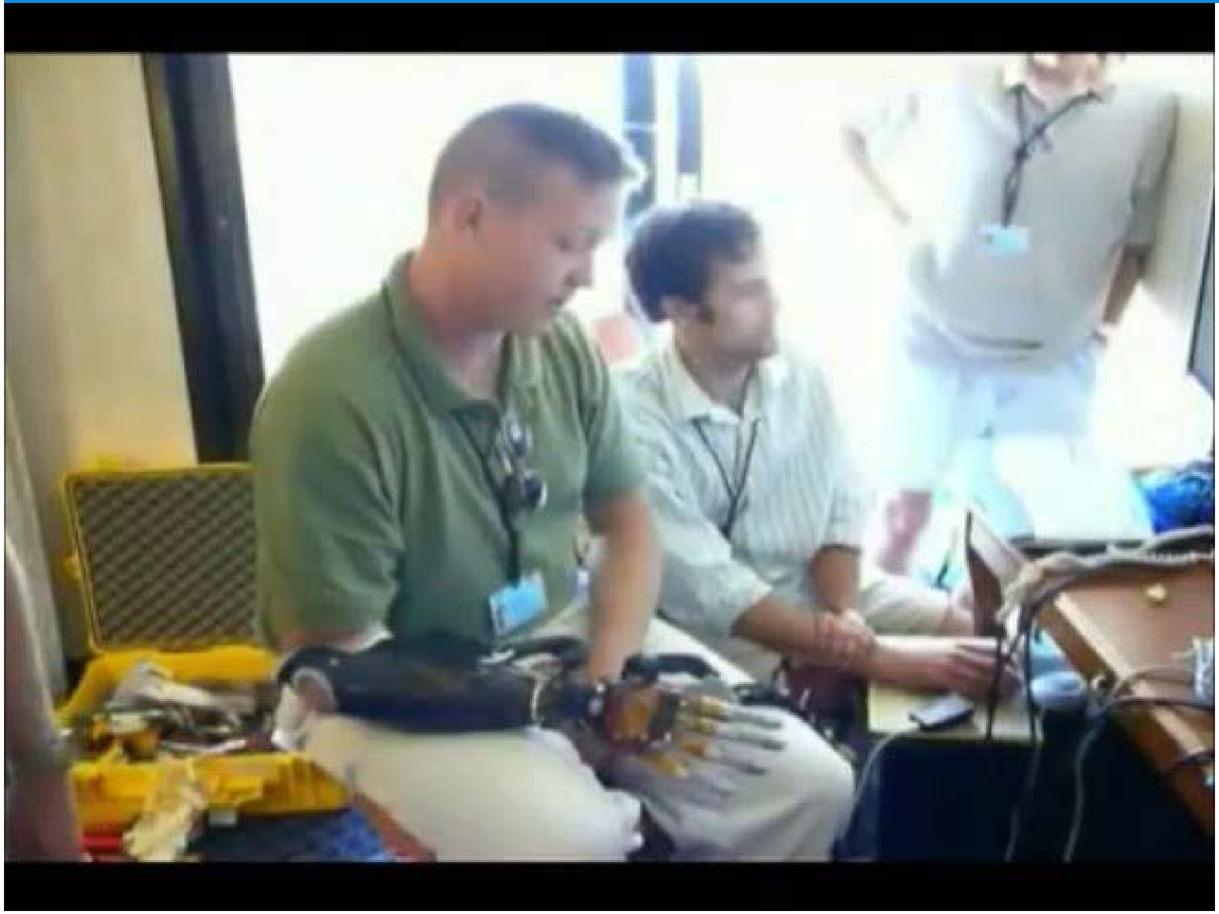
The farther up the nervous system we go, the smaller the signal intensities get, and the less direct the coupling between signal detected and action.

V-> 5mV -> 100uV -> 50uV

Simple explanation signal complexity



A State-of-the-art BMI



(Intrinsic Hand– JHU-APL, 2009)

EMG
controlled
Lower limb
Pattern
recognition
1st use
Not flexible

But what about feedback?

Think carefully about how and why you are feeding information back to the user.

The goal of feedback should be to provide some combination of better control outcomes and lower control effort and more situational awareness.

Different kinds of feedback

- Visual
- Auditory
- Position
- Force

What does this mean? The more relevant the feedback, the less conscious effort expended. Visual tasks should use visual feedback, motor tasks should use proprioceptive feedback, etc etc

Exo-Skeletons

(Hardiman – General Electric, 1965)

(XOS-2 – Sarcos/Raytheon 2011)

What is an exoskeleton?

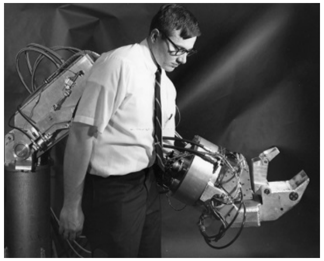
In an engineering context, exoskeletons are wearable robotic systems to improve the strength, endurance, or performance of human operators.

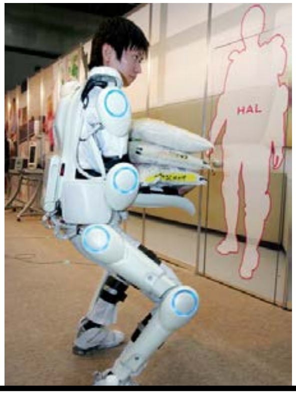
Two broad classes (these are very broad)

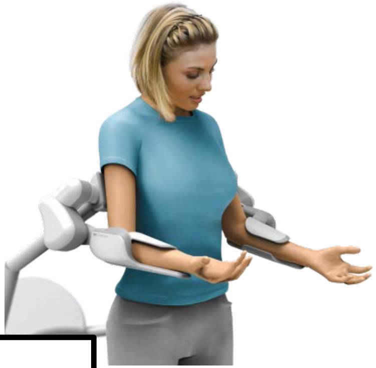
Rehabilitation Systems
- Lokomat (Hokoma)
- T-wrex (UC-Irvine)
- HAL (Cyberdyne Systems)

Enhancement Systems
- XOS-2 (Raytheon-Sarcos)
- HULC (Lockheed-Martin)
- *Ekso (Ekso Bionics)

History of Exoskeletons







- 1965, Hardiman, GE – envisioned to enhance huma
performance, c
ever had 1 low
arm working. W
actually a bilate
force feedback
master-slave
telemanipulator. Had terrible instability issues.

The exoskeleton, called ‘xxxxxx’ mimics the movements of its wearer, presenting a literal union of man and machine. Thus, the human’s flexibility, intellect, and versatility are combined with the machine's strength and endurance.

(position estimation only for force minimization)

)15... Chiron
Delft H-
ptics program
pedance
sed gravity
mpensation

Why build exoskeletons?

Robotic systems can perform tasks that are beyond the abilities of an unenhanced human being – but robots have a very hard time operating in an unconstrained environment.

Many tasks require a constant human in the loop for both safety and technical performance.

Exoskeletons *(should?)* provide the advantages of perfect positional feedback, no sensory delays, intuitive ranges of motions, high quality visual feedback

Why aren't we all Ironman?

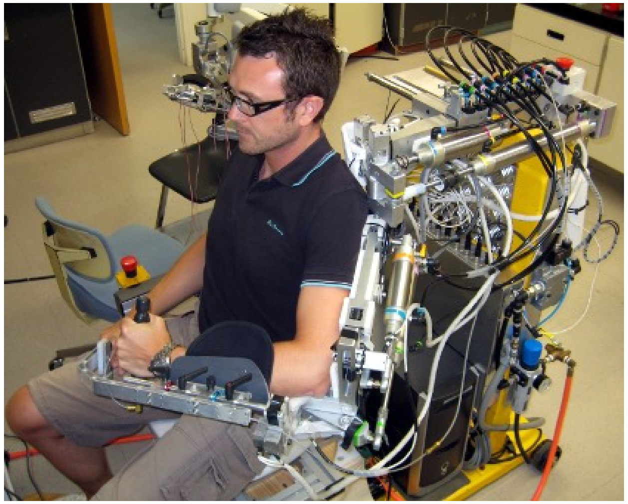
Fitting an exoskeleton is difficult – if you attach the system rigidly, the alignment of the joints has to be nearly perfect, or it is uncomfortable. Many existing systems use this technique.

Power density! A human being can provide extremely large forces in a very compact package, and we carry our own power supply. Current enhancing exoskeletons rely on external supply, or have a very limited working time

Control is hard! Assistive exoskeletons have, by definition, a forward feedback loop, which can become unstable

Different types of exoskeletons

Upper limb



(T-wrex – Hocoma)

Lower Limb

(Eksos – Eksos Bionics)

Full Body

(XOS-2 – Sarcos/Raytheon)

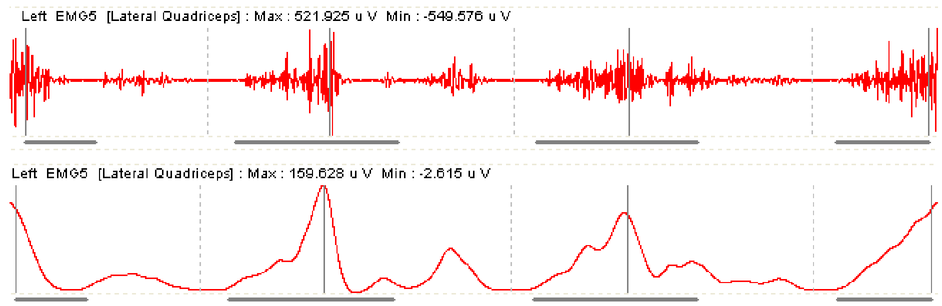
State of the art exoskeleton

(XOS-2 – Sarcos/Raytheon)

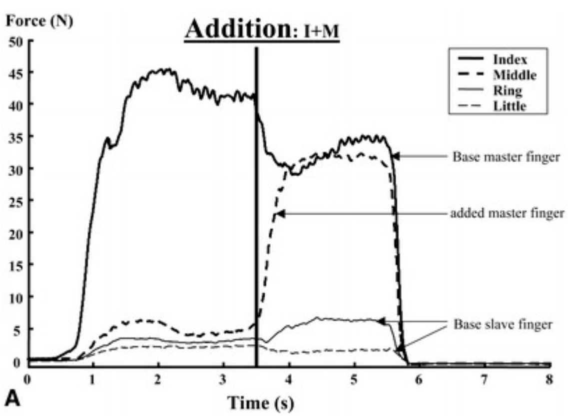
Biosignals (remember these?) are control signals

Control signals to estimate intent for exoskeleton control.

- •EMG
- •Force
- •EEG
- •MEG



(Typical EMG traces, Motion Lab Systems)



(Typical force traces, Sheng et al, 2003)

(Typical EEG traces, Center for Health Psychology)

H-Haptics

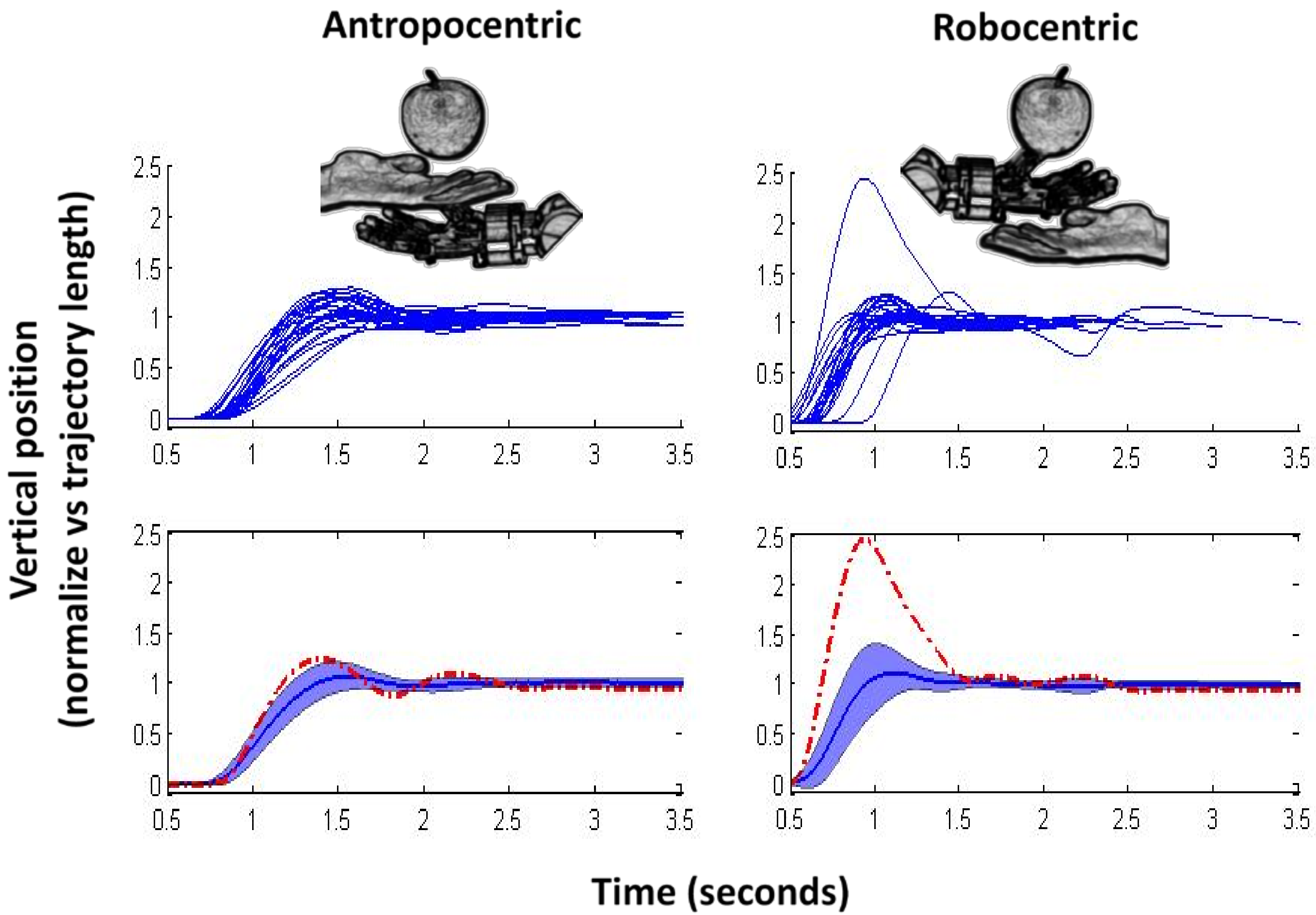
My research

Currently developing a powered exoskeleton to work in a hospital or a workshop environment

So far, we have a system that compensates gravity forces, and requires no adjustment for individual users. And we are exploring how to feed back information about the exoskeleton to the operator

Next steps are to understand how changing the force we feel affects how we change our movements

How design influences performance



10 minute design challenge

Build an Iron-Arm (design a 1 degree of freedom exoskeleton to support a persons elbow joint)

1. Define the task:
   Help a warehouse worker life large boxes of potatos from the ground to a truck

10 minute design challenge

1. Define the task
2. What kind of control type do we want?
3. What kind of input signal do we want to use?
4. What sort of feedback do we give to the operator?
5. How do we define the human-robot interface?

Contact and references

Jack F. Schorsch

Biosignals and Bioinstrumentation
– Principles of Bioinstrumentation; Richard Normann
Analyzing random data
- Random Data: Analysis and Measurement Procedure; Bendat & Piersol