A little about me...

History and Previous Work

2002, BS(E) Biomedical Engineering, Tulane University

2002 - 2006, Research Engineer Loyola University Medical Center Chicago, IL

2007, MS(E) Medical Device and Diagnostic Engineering, University of Southern California

2007 - 2011, Research Manager Rehabilitation Institute of Chicago Chicago, IL

2011, Started PhD at TU Delft
About today...

Our topics for today

- Biosignals
  - What are they, where do they come from, and what could we do with them?
- **Body Machine Interface / Brain Computer Interface**
  - 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
About today...

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?

Anywhere 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
Biosignals

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 propagates 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.
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!
**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!

![Image of in-line force sensor](image)

**(In-line force sensor, Mega Electronics)**

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**(Typical force traces, Sheng et al, 2003)**

![Graph showing force traces](image)
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 (BMIs) or Brain Computer Interfaces (BCIs) are techniques and technologies for determining the intent of a human. These systems are currently 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

- More information available
- Easier to measure
- Harder to determine intention
- Many signals overlapping

BMIs

Brain → Spinal / Peripheral Nerves → Muscles → Endpoint Force → Endpoint Position

Central nervous system
Brain
Spinal cord
Peripheral nervous system
Peripheral nerve

The Human Controller 21-May-2014
A State-of-the-art BMI

EMG controlled
Lower limb
Pattern recognition
1st use
Not flexible

(Intrinsic Hand - JHU-APL, 2009)
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.
Exoskeletons

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)
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.
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)

Full Body

(XOS-2 – Sarcos/Raytheon)

Lower Limb

(Eksos – Eksos Bionics)
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

Antropocentric

Robocentric

Vertical position (normalize vs trajectory length)

Time (seconds)
10 minute design challenge

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

1. Define the task:
Help a warehouse worker lift large boxes of potatoes 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