Course proposal

Neuroengineering

Scientific Area:

Bioengineering – Biosignals and biomedical systems

Weight:

Credits:	6 ECTS
Contact time:	56h
Autonomous time:	112h
Total time:	168h

Rationale

Neuroengineering is a recently developed and rapidly changing domain in Biomedical Engineering that employs engineering methodologies to address the problems of "understanding, repairing, enhancing or otherwise exploring the properties of neural systems". Its main goal is to develop tools to investigate the human brain and artificial devices to interact with it in order to repair and/or enhance its function, particularly through brain-computer interfaces and neuroprosthetics.

Neuroengineering draws on disciplines ranging from *Neuroscience* to *Biophysics*, *Electrical Engineering*, *Computer Science*, *Materials Science*, and *Tissue Engineering*. Faculty with relevant and complementary expertise in engineering within IST (mostly DBE, but also DEEC and DEI) will join with neuroscience faculty from CNP and FMUL, in order to provide a course on *Neuroengineering*.

Objectives

The main objective of the course is to provide students with comprehensive background knowledge of the most important areas in the field of *Neuroengineering*, including the existing challenges and the main concepts and techniques that can be used to address them.

Students successfully completing the course are expected to: 1) have basic knowledge about the organization, structure, function and pathological modifications of neural systems; 2) have general knowledge about the principles, methodologies and applications of the main engineering techniques used to study and interact with neural systems, with the objectives of brain monitoring, diagnosing, modulating, repairing, enhancing or interfacing with machines; and 3) be prepared to critically evaluate different problems and techniques in *Neuroengineering*.

Synopsis

The course will be organized as a series of teaching modules addressing a number of specific topics in *Neuroengineering*, primarily aimed at students with a background in engineering (1st cycle / BSc in engineering). Each module will last 1-2 weeks, and will be organized by an expert in the field.

The course will take a multidisciplinary approach, targeting state-of-the-art techniques, and it will include conventional lectures as well as seminars by invited experts and journal club classes for the discussion of relevant scientific literature.

Programme (modules)

1. **Opening (Fernando Lopes da Silva)**
    a. Current challenges for neuroengineering
2. **Neuroscience basics I (Zach Mainen, CNP) – 1 week**
    a. Neural systems and behavior
    b. Brain cells and circuitry
3. **Neuroscience basics II (Ana Sebastião and Isabel Pavão Martins, FMUL) – 1 week**
    a. Neural communication, plasticity and degeneration
    b. Cognitive function and dysfunction
4. **Computational neuroscience (Tiago Maia and Christian Machens, FMUL and CNP) – 1 week**
    a. Neural coding and neural networks
    b. Computational cognitive neuroscience
5. **Neuroimaging (Patrícia Figueiredo and Rita Nunes, IST – DBE) – 2 weeks**
    a. Electroencephalography (EEG) and magnetoencephalography (MEG): invasive and non-invasive recordings of spontaneous and event-related activity.
    b. Magnetic resonance imaging (MRI): image formation and reconstruction; structural, functional, perfusion and diffusion imaging contrasts.
    c. Diffuse optical imaging (DOI) by near infrared spectroscopy (NIRS)
    d. Positron emission tomography (PET): molecular imaging using radiotracers for brain metabolism and function.
6. **Neural monitoring and diagnosis (Ana Fred, IST - DBE) – 1 week**
    a. Statistical inference and model-based classification methods for diagnosis and monitoring of brain disorders

b. Detection and monitoring of brain activity patterns for emotion assessment and human identification

c. Unsupervised learning of brain activity patterns and longitudinal studies

7 Neural interfaces (João Sanches, Fernando Lopes da Silva, IST – DBE) – 1 week

a. Fundamentals of brain computer interfaces. Neurophysiology, EEG data acquisition and signal processing

b. Direct EEG Interfaces, VEP, P300 and ERD/ERS

c. Motor imagery and rehabilitation

d. Applications

8 Neural modulation (Agostinho Rosa, IST – DBE) – 1 week

a. Neurofeedback using EEG and NIRS.

b. Neural stimulation: Deep Brain Stimulation (DBS), Transcranial Direct Current Stimulation (TDCS), Transcranial Magnetic Stimulation (TMS)

c. Self-adaptive immersive neural stimulation

d. Clinical and performance enhancement applications

9 Neural tissue engineering (Margarida Diogo, IST – DBE) – 1 week

a. Biomolecular-based strategies (e.g. neurotrophic factors) for neural regeneration

b. Cellular-based strategies for neural regeneration (stem cell-based and mature neural cell-based strategies) and disease modeling

c. A-cellular biomaterial-based strategies for neural regeneration

d. Advanced tissue engineering strategies combining biomaterial scaffolds, biochemical cues and cells

10 Microsystems and nanotechnology for neuroengineering (João Pedro Code, IST – DBE) – 1 week

a. Nanoparticle engineering for interaction with neural cells, targeted delivery of drugs, and advanced molecular imaging technologies

b. Microsystems for neuroscience on a chip and for microengineereing neural development

11 Cognitive robotics (José Alberto Santos-Víctor, IST – DEEC) – 1 week

a. Sensorimotor coordination

b. Non-verbal communication

c. Tools for rehabilitation

12 Complex brain networks (Arlindo Oliveira and Alexandre Francisco, IST – DEI) – 1 week

a. Theory and basic concepts of complex networks
b. Properties, representation, processing and analysis of large networks
c. Applications to brain networks

Evaluation method:

- Exam (70%): two dates during exam period, covering all the modules' topics.
- Student presentation (30%): two sessions during the last week of the semester, paper or essay regarding one of the course topics

Bibliography:

- Neural Engineering, Bin He Ed., 2nd ed. 2013 Edition (ISBN-13: 978-1461452263)
- Lectures notes provided by the course faculty.

Schedule (tentative):

	Month	Day	Module	Responsible
1	Sep	13	Introduction	Fernando Lopes da Silva
		14		
2		20	Neuroscience basics I	Zach Mainen
		21		
3		27	Neuroscience basics II	Ana Sebastião
		28		
4	Oct	4	Computational Neuroscience	Tiago Maia
		5		
5		11	Neuroimaging I	Patricia Figueiredo
		12		
6		18	Neuroimaging II	Rita Nunes
		19		
7		25	Neural monitoring and diagnosis	Ana Fred
		26		
8	Nov	1	Neural interfaces	João Sanches
		2		
9		8	Neural modulation	Agostinho Rosa
		9		
10		15	Neural tissue engineering	Margarida Diogo
		16		
11		22	Microsystems and nanotechnology for neuroengineering	João Pedro Conde
		23		
12		29	Cognitive robotics	José Santos-Víctor
		30		
13	Dec	6	Complex brain networks	Arlindo Oliveira e Alexandre Francisco
		7		
14		13	Student presentations	all
		14		