HUMANITAS UNIVERSITY

MEDTEC SCHOOL

Course: Bioelectric Signal Processing and Modeling

Year (1st-2nd-3rd-4th-5th-6th): 2nd

Period (1st-2nd semester – annual): 2nd

Credits: 4

Objectives

The goal of this course is to enable students to master basic signal processing and modeling methods aimed at extracting meaningful information from biomedical signals. The course covers the fundamentals of systems analysis for modeling specific mechanisms observable from the human organism, and provides basic rationales for developing specific approaches aimed at improving medical diagnosis, treatment and rehabilitation. The course provides a selected overview of some of the most important signal processing tools. The main paradigm theme develops through critical conceptual frameworks related to Mathematics and Statistics. Modeling algorithms span from simple modeling mathematical constructs to modeling more complex frameworks inspired by physiology. Each topic is treated both theoretically and practically, with pivotal examples relative to the neural and cardiovascular systems, focusing on the central and peripheral autonomic nervous system.

Expected learning results

Students will be able to understand, design, and implement basic signals and data processing algorithms and mathematical tools in the context of Medicine and Biology. In particular, students will learn how to:

• Identify a specific problem in dealing with targeted medical information and apply the most suitable algorithm among the various ones explained in the course. (DD2)

• Evaluate the pros and cons of alternative approaches. Identify specific classes of common problems in biomedical information processing in a wide range of applications for different systems or organs, at various scales of investigation. (DD3)

• Properly manage and apply basic methods and algorithms in order to perform statistical analysis and modeling by basic signal processing of evenly and unevenly sampled time series. (DD2)

• Understand various physiological and clinical settings from the standpoint of the information extracted by the learned algorithms. (DD1)

Prerequisites

At the time of attendance, students are required to be familiar with basic principles, methods and algorithms of mathematics, statistics and experimental physics. The course of Mathematics is a prerequisite to attend the oral exam.

Contents

Introduction to Modeling of Biological Systems

1. Signals definition and classification, examples from the Biological world. Where biomedical signals come from:
   - Models and methods for the analysis of membrane potentials. The Hodgkin-Huxley model. Impulse propagation and conduction in fibers. Neuron models and networks. Extra-cellular potentials. Unraveling the Neural Code.
   - The Electromyographic (EMG) Signal. Acquisition systems and useful information.
   - The Electro- and Magneto- Encephalographic (EEG, MEG) signals. Acquisition systems and useful information.
   - The Electrocardiographic signal. Acquisition systems and useful information.
2. Elements of Signal Processing
   - Analog to digital conversion: from acquisition to digitalization, sampling, aliasing, quantization error.
   - Stochastic signals and their properties: mean, variance, autocorrelation, stationarity, ergodicity.
   - Systems Theory: LTI, Stimulus-Response models. Transfer Function Models
   - From time to frequency: the Fourier transform.
   - Non-parametric spectral analysis: power spectral density, Periodogram, Bartlett, Welch for power spectral density, cross spectrum, and coherence.
3. Modeling and signal processing of human physiology
   - The Electromyographic (EMG) Signal.
   - The Electro- and Magneto- Encephalographic (EEG, MEG) signals: Methods for the evaluation of electric and magnetic fields. Identification of signal rhythms in different frequency bands. Evoked potentials.
   - The Electrocardiographic signal. Heart rate variability: regulation on the heart rhythms by the autonomic nervous system. Time and frequency analyses. Statistical approaches to estimate heartbeat dynamics.
   - Cardiovascular covariates: Respiration, Arterial Blood Pressure, Galvanic Skin Response.

Practical Applications

• Practical examples of basic signal processing

• Practical examples of simple mathematical models

• Examples on the Electromyogram.

• Basic cardiovascular models for ECG processing: from ECG to HRV

• Basic methods for EEG analysis: Evoked and Event Related Potential, Spectral analysis.

Teaching Methods

Traditional lectures are focused on teaching basic mathematical and biomedical engineering concepts. Students are encouraged to actively participate to the lectures with questions and comments. Lectures are supported by parallel exercise sessions where the students are required to actively engage in solving specific challenges based on the theory they were previously exposed to.

Assessment

During the course, exercise tests are assigned on selected topics covered up to each milestone point. A self-evaluation of these tests will allow the student to evaluate the degree of understanding of the computational aspects of the course. These tests do not contribute to the final grade. The final exam can be taken in each of the scheduled sessions in June-July (highly recommended), September and January-February. The evaluation will be given on the basis of a final oral test over the topics presented in the Lectures and Exercise hours. During the examination, the students will have to:

• Demonstrate the degree of knowledge and comprehension of the key aspects of the course, presenting the used methodologies in a clear and exhaustive way

• Demonstrate their ability to apply the learned notions to solve exercises and real problems, on any of the topics covered in the course.

Texts

Recommended material:

Lecture Slides and Notes posted on the School website

Optional Material:

Tompkins W.J., Biomedical Digital Signal Processing, Editore: Anno edizione: 1993, Editore: Prentice

Hall, Anno edizione: 1993

Rangayan R.M., Biomedical Signal Analysis. Second Edition, Editore: Wiley Interscience