Aeronautics Institute of Technology – ITA
Division of Electronics Engineering – IEE

ET-287 – Signal Processing using Neural Networks

Course plan - 2^{nd} semester, 2024

Professor:
Sarah Negreiros de Carvalho Leite
Department of Telecommunications| Room 221
`sarah.leite@gp.ita.br`

Prerequisites:

- ET-290 Digital Communication
- ET-286 Digital Signal Processing

Weekly hours: 2-0-2-4

Weekly schedule:
Monday - 2 PM - 5 PM
Room *Laboratório de Bioengenharia.*

Class rescheduling:

- Holidays and bridges: will be rescheduled as needed.
- Activities and projects are still due.

Syllabus:
This course combines classical signal processing techniques with neural network tools to propose solutions for classification, prediction, diagnostic support, preventive fault detection, pattern recognition. Topics covered include spatial filtering, temporal filtering, filter banks, spectral estimators, autoregressive models, Multilayer Perceptron networks, Convolutional Networks, and Recurrent Networks. Projects will be developed using signals of various natures, such as audio, speech, text, images, video, biological signals, cardiac signals, brain signals, seismic signals, radar data, etc.

Contents:

1. Introduction to Python with a brief review of linear algebra.
2. Introduction to neural networks. Perceptron.
3. Filtering and spectral estimators.
4. Feedforward Neural Networks.
   - Multilayer perceptron.
   - Neural networks with radial basis activation function.
   - Extreme learning machines.
   - Convolutional neural networks.
5. Recurrent Neural Networks:
   - Hopfield
   - LSTM
   - GRU

Projects:

Project 1 (P_1): Proposal for analysis and evaluation of a dataset to become familiar with the Python language and libraries numpy, pandas, and matplotlib.

Project 2 (P_2): Propose a classification problem to implement and gain an understanding of the perceptron model and its parameters. Utilize classical signal processing techniques to analyze the signal in both the time and frequency domains, focusing on feature extraction methods.

Project 3 (P_3): Proposal for a classification or prediction problem to be solved using an MLP network. Objective of familiarization with the Tensorflow or Pytorch libraries, understanding and analysis of the impact of hyperparameters and network topology. Address class imbalance and preprocess the data for optimal performance.

Project 4 (P_4): Proposal for a classification or prediction problem using a CNN (1D, 2D, or 3D). Using transfer learning for object recognition with pre-trained networks. Address image processing methods.

Project 5 (P_5): Proposal for a dynamic prediction problem. Short and long term memory.

Final Project: Addressing a real problem in signal processing or telecommunications. Students will complete a project by choosing a theme and a dataset, defining the best neural network structure to solve the problem, configuring network hyperparameters, and critically analyzing the results. During the project, content will be covered to enable the execution of the chosen project, referring to: exploratory data analysis, data preprocessing, variable treatment, missing data, variable selection techniques, class balancing, etc.

General goals:
Introduce the concepts and techniques associated with classical neural networks and Deep Learning, along with their applications in the context of signal processing. Empower the student to model and design neural networks to solve real-world problems involving classification, pattern recognition, function approximation, and time series prediction. Students will learn to program neural networks, configure parameters, and critically evaluate results.

Methodology:
Lecture sessions will alternate with hands-on practical classes, fostering active learning and the cultivation of logical reasoning essential for tackling real-world problems. Throughout the course, students will engage in constructing various neural network techniques using Python, machine learning libraries, digital signal processing methods and publicly available datasets, promoting a deeper understanding through hands-on application and discussion.

Examination System:

- **First Term**:

$$B_1 = 0.1.PP + 0.2.P_1 + 0.3.P_2 + 0.4.P_3$$

- **Second Term**:

$$B_2 = 0.5.P_4 + 0.5.P_5$$

- **Exam**:
  - Report and codes related to the development of the final project (R).
  - Seminar: Oral presentation of the final project (S).

$$E = 0.5S + 0.5R$$

- **Final grade:**

$$MF = \frac{B_1 + B_2 + E}{3}$$

The project and manuscript can be developed in groups of up to 3 students.

The group should be defined and indicated in the 'Project proposal description' and it should not be changed without consulting the professor.

Table 1: Contents per week

Week	**Content**	**Delivery/evaluation**
1	Introduction and Presentation.	
2	Review of Linear Algebra with Python.	
3	Introduction to neural networks.	Project 1
4	The perceptron.	
5	Feedforward Neural Networks.	Project 2
6	Multilayer perceptrons.	
7	Multilayer perceptrons.	Project proposal description (PP)
8	Open Discussion.	Project 3
	Semaninha	
1	RBF and ELM.	
2	Convolutional Neural Networks.	
3	Convolutional Neural Networks.	Project 4
4	Recurrent Neural Networks.	
5	Recurrent Neural Networks.	Project 5
6	Final project development and discussion.	
7	Final project presentation.	Seminar
8	Open Discussion.	
	Exam weeks	Report and codes of Final Project

Subject to change, aiming to have a good pace or due to external course events.

References:

1. OPPENHEIM, Alan V. Discrete-time signal processing. Pearson Education India, 1999.
2. ZAKNICH, Anthony. Neural networks for intelligent signal processing. World Scientific, 2003.
3. HAYKIN, Simon. Neural Network: a comprehensive foundation. Pearson, 2004.
4. LUO, Fa-Long; UNBEHAUEN, Rolf. Applied neural networks for signal processing. Cambridge university press, 1998.
5. HAYKIN, Simon. Neural Network: a comprehensive foundation. Pearson, 2004.
6. AGGARWAL, Charu C. et al. Neural networks and deep learning. Springer, 2018.
7. GOODFELLOW, Ian; BENGIO, Yoshua; COURVILLE, Aaron. Deep learning. MIT press, 2016.
8. Papers related to the topics covered.