ENGINEERING PROGRAMME

2022-2023

Year 2 / Year 3

Specialisation option

Data Analysis and Applications in Signal and Image Processing

OD DATASIM

PROGRAMME SUPERVISOR
Said MOUSSAOUI

Autumn Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 73 / 93	12	Core course	ARSIG ATRIM CSOPT MSTAT	Signal representation and analysis Image processing and analysis Scientific computing and numerical optimization Statistical data modelling and analysis
UE 74 / 94	13	Core course	AMULT APSTA IMINV PRTSI1 SIBIO	Multi-sensor data analysis Machine learning theory and practice Imaging and Inverse Methods Project in signal and image processing Biomedical signal analysis

Spring Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 103 / 83	14	Core course	APPLI AUDIO IMBIO MPSET PRTSI 2	R&D applications Audio content analysis and Information Retrieval Biomedical imaging Modelling and prediction of time-series Project in signal and image processing

Signal representation and analysis [ARSIG]

LEAD PROFESSOR(S): Sébastien BOURGUIGNON

Objectives

Extracting relevant information from a data set is a key step for efficient data processing. For example, the use of specific analysis methods is crucial for event detection in a noisy environment, extraction of characteristic features for statistical learning and classification, noise reduction or data compression.
This course introduces a set of mathematical (analytical and numerical) tools for representing a signal, an image or, more generally, a data set, in order to extract its meaningful and useful information. Different analysis tools are presented, both in their mathematical and informational foundations and in their practical numerical implementation, through application examples taken from real data processing problems.
The first part of the course deals with the analysis of stationary signals, through Fourier analysis and high-resolution spectral analysis. Time-frequency and time-scale representations are studied for the analysis of non-stationary data. Finally, some elements concerning the more recent sparse representation framework are introduced, which generalise the former representations to more complex issues, in particular adapted to modern problems concerning big data processing.

Course contents

1. Spectral analysis for stationary signals: Fourier analysis, high-resolution methods. Lab work: detection of multiple oscillating components in noise; application to exoplanet detection from time series.

2. Time-frequency analysis: linear (short-term Fourier transform) and quadratic (Wigner-Ville and Cohen's class) representations. Lab work: comparison of different time-frequency representations; application to automatic music transcription.

3. Non-stationary signals: time-scale representations and wavelet transforms. Lab work: Discrete Wavelet Transform and multiscale analysis; application to signal denoising and image compression.

4. Toward more general models: sparse representations. Lab work: denoising through projection into orthogonal bases and into redundant spaces; application to restoration of galactic emission spectra.

Course material

A.V. Oppenheim and R.W. Schafer. Discrete-time signal processing, Prentice Hall, 2010.
S. Marcos. Les méthodes à haute résolution : Traitement d'antenne et analyse spectrale, Hermès, 1998.

L. Cohen, Time-Frequency analysis, Prentice-Hall, 1995.
N. Martin et C. Doncarli, Décision dans le plan temps-fréquence, Hermes, 2004.

S. Mallat, A Wavelet Tour of Signal Processing: The Sparse Way, Academic Press, 2008.

M. Elad, Sparse and Redundant Representations, Springer, 2010.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	10 hrs	12 hrs	0 hrs	2 hrs

Image processing and analysis [ATRIM]

LEAD PROFESSOR(S): Diana MATEUS LAMUS

Objectives

This course is an introduction to the essential techniques for digital image processing. It covers how images are formed, stored, processed and used. We will review different types of image processing methods, including techniques for image enhancement, filtering, denoising, and some segmentation bricks. The course is composed of a series of lectures accompanied by significant hands-on experience to put into practice and analyse the taught techniques.

Course contents

Content:
-Introduction to digital images
- Morphological operators
- Spatial filtering
- Spectral filtering
- Geometric transformations
- Segmentation methods

Course material

[1] Digital Image Processing, 4th Ed. Gonzalez and Woods © 2018, ISBN: 9780133356724
[2] Computer Vision: Algorithms and Applications (Texts in Computer Science). 2011th Edition. by Richard Szeliski
[3] D. Forsyth, J. Ponce, Computer vision: a modern approach, Prentice Hall 2003.

Assessment

Collective assessment: EVC 1 (coefficient 0.6)

Individual assessment: EVI 1 (coefficient 0.4)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	10 hrs	12 hrs	0 hrs	2 hrs

Scientific computing and numerical optimization [CSOPT]

LEAD PROFESSOR(S): Said MOUSSAOUI

Objectives

This course focuses on scientific computing and numerical optimization methods that are used in signal and image processing. It firstly provides a theoretical description of the methods and then addresses some examples such as non-linear curve fitting and signal/image denoising.

Course contents

1. Scientific computing
- Matlab
- Python

2. Unconstrained optimization
- basic concepts: differential calculus, mathematical properties, optimality conditions
- iterative methods (first and second order methods, descent direction, line search, trust region)
- applications (usual functions, parametric curve fitting, signal denoising)

3. Constrained optimization
- exterior penalty methods
- interior-point methods
- applications to image restoration

4. Global optimization
- interval methods
- evolutionary methods
- Monte Carlo methods

Course material

[1] J. Nocedal and S. J. Wright. Numerical Optimization. Springer series in operations research, Springer, 1999
[2] S. Boyd and L. Vendenberghe. Convex Optimization. Cambridge University Press, 2004
[3] P. Venkataraman. Applied Optimization with Matlab Programming, John Wiley and Sons, 2001

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	8 hrs	12 hrs	0 hrs	2 hrs

ENGINEERING - OD DATASIM

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

Statistical data modelling and analysis [MSTAT]

LEAD PROFESSOR(S): Eric LE CARPENTIER

Objectives

This course addresses the characterization and the processing of random signals by means of statistical tools. It provides the theoretical foundations used in practical problems to estimate a quantity of interest and to retrieve sought information.
Applications concern: biomedical signal and image processing (diagnosis, tools to assist the disabled), music signal processing (recording, restoration, coding), positioning systems, etc.
At the end of the course the students will be able to:
- Provide a statistical description of a random process
- Solve a statistical estimation problem in a practical situation
- Derive a numerical algorithm to calculate and to characterize the solution

Course contents

- Probability theory: random vectors, density, mean, variance.
- Time analysis, frequency analysis: random signals, autocorrelation, power spectral density.
- Classical estimation, Bayesian estimation: maximum likelihood (ML) estimation, minimum mean square error (MMSE) estimator, maximum a posteriori (MAP) estimator, linear minimum mean square error (LMMSE).
- Markov chains, Markov processes.
- Statistical filtering: Bayes, Kalman, particles.

Course material

[1] Probability, Random Variables and Stochastic Processes. A. Papoulis, S.U. Pillai. Mc Graw Hill.
[2] Fundamentals of Statistical Signal Processing, Vol.1: Estimation theory, S. Kay, Prentice Hall.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	10 hrs	10 hrs	0 hrs	2 hrs

Multi-sensor data analysis [AMULT]

LEAD PROFESSOR(S): Said MOUSSAOUI

Objectives

This course focuses on multi-sensor data analysis techniques using so-called source separation techniques. These recent methods - principal component analysis, independent component analysis and non-negative matrix factorization - make it possible to exploit sensor redundancy to analyse the content of data revealing mixtures.

The second part of the course addresses applications for signal and image processing and shows how to adapt the methods of analysis to the constraints of the applications.

Course contents

1. Source separation methods
a) Algebraic methods
b) Iterative methods
c) Statistical approaches (maximum likelihood and Bayesian estimation)

2. Applications for signal analysis
a) Spectrometry
b) Biomedical signals

3. Applications for hyperspectral imaging
a) Concepts of remote sensing
b) Geometrical approaches
c) Hyperspectral image analysis by source separation

Course material

[1] P. Comon and C. Jutten, Séparation de sources 1: concepts de base et analyse en composantes indépendantes, Traité IC2, série Signal et image, 03-2007
[2] P. Comon and C. Jutten, Séparation de sources 2: au-delà de l'aveugle et applications, Traité IC2, série Signal et image, 03-2007
[3] A. Hyvarinen, J. Karhunan, and E. Oja, Independent Component Analysis. Johns Willey & Sons., 2001.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	10 hrs	10 hrs	0 hrs	2 hrs

Machine learning theory and practice [APSTA]

LEAD PROFESSOR(S): Diana MATEUS LAMUS

Objectives

The aim of this course is to provide students with the key notions of machine learning, essential today in dealing with the ubiquitous collection of increasing amounts of data. The course will introduce the different types of machine learning and their applications in the context of signals and images. We will review the most influential methods for unsupervised and supervised learning. The sessions will alternate between lectures, practical exercises, and mini-projects in Python. Although the techniques will be presented from a broad and general perspective, the applications will focus on images and biomedical data.

Course contents

- Introduction to machine learning
- Supervised and unsupervised methods
- Data representation, variable selection, and dimensionality reduction
- Evaluation measurements
- Probabilistic and linear classification methods
- Support Vector Machines (SVM)
- Decision trees and random forests
- Neural networks
- Introduction to deep learning
- Autoencoders (deep learning)

Course material

[1] Bishop C. : Pattern Recognition and Machine Learning. Springer, 2006.
[2] Kevin P. Murphy, Probabilistic Machine Learning: An Introduction, 2022

Assessment

Collective assessment: EVC 1 (coefficient 0.5)

Individual assessment: EVI 1 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	10 hrs	10 hrs	0 hrs	2 hrs

Imaging and Inverse Methods [IMINV]

LEAD PROFESSOR(S): Sébastien BOURGUIGNON

Objectives

Inverse methods are used when information about an object under study is acquired indirectly, by measuring the effects of a physical phenomenon whose causes are sought. This measurement principle can be found in many applications: optics, acoustics, medical imaging, oceanography, astronomy, non-destructive testing of materials, etc. This is the case for most imaging devices, where the aim is to map physical properties inside an object under study from measurements located at its periphery (e.g., X-ray tomography, or CT scan). This is also the case for methods aiming to restore a signal, an image, a data set from a version that was downgraded, distorted and filtered by the acquisition device (e.g., PSF of a microscope or of a telescope).

This course aims to introduce students to basic and more advanced tools to address an inversion problem, from the definition of the direct problem (physical modelling) and general information theory elements (incomplete data, ill-posed problem, statistical inference), to the resolution principle essentially based on regularization, up to the efficient numerical computation of the solution by means of specific algorithms.

Course contents

1. General points: ill-posed problems, regularization, a priori information

2. Deconvolution: standard (linear) methods, quadratic regularization

3. Non-linear methods, spike train deconvolution, sparsity

4. Image restoration and tomography

Course material

A. Tarantola, Inverse Problem Theory and Model Parameter Estimation, SIAM, 2005.
J. Idier (Ed.), Bayesian Approach to Inverse Problems, ISTE Ltd and John Wiley & Sons Inc, 2008.
M. Bertero, P. Boccacci, Introduction to Inverse Problems in Imaging, CRC Press, 1998
P.C. Hansen, Discrete Inverse Problems: Insight and Algorithms, SIAM, 2010
J. M. Mendel, Optimal Seismic Deconvolution, Academic Press, 1983.
A. C. Kak et M. Slaney, Principles of Computerized Tomographic Imaging, IEEE Press, 1988.

Assessment

Collective assessment: EVC 1 (coefficient 0.3)

Individual assessment: EVI 1 (coefficient 0.7)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	8 hrs	12 hrs	0 hrs	2 hrs

Project in signal and image processing [PRTSI1]

LEAD PROFESSOR(S): Said MOUSSAOUI

Objectives

The aim of this course is to undertake a project related to the processing of real data: audio signals, biomedical images or signals, hyperspectral images etc. This project begins in the autumn semester and is pursued in the spring semester.

Course contents

The projects concern the processing of real data such as:

1. Spectral data and hyperspectral images: deconvolution, decomposition and separation
2. Physiological signals: EEG, EMG for BCI and Prosthesis control
3. Audio signal: segmentation, speech recognition, content analysis
4. Medical image analysis: image segmentation, pattern recognition, etc

Course material

[1] Fundamentals of statistical signal processing - Vol I. Estimation theory. S. KAY. Prentice Hall, 1993.
System identification, theory for the user. L. LJUNG Prentice Hall, Englewood Cliffs, New Jersey, 1987 (1st ed.) - 1999 (2nd ed.).
[2] Approche bayésienne pour les problèmes inverses. J. IDIER. Traité IC2, Série traitement du signal et de l'image, Hermès, 2001.
[3] Pattern Classification. R.O. DUDA, P.E. HART, D.G.STORK, Willey 2001.
Analyse d'images, filtrage et segmentation. Sous la direction de J.P. COQUEREZ et S. PHILIPP, Masson 1995

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	1	0 hrs	0 hrs	0 hrs	32 hrs	0 hrs

ENGINEERING - OD DATASIM

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Biomedical signal analysis [SIBIO]

LEAD PROFESSOR(S): Said MOUSSAOUI

Objectives

This course presents biomedical signal acquisition and processing techniques.

Course contents

The content of the course covers application examples such as:

1. EMG signal modelling: measure, characterisation, decomposition and applications to prosthesis control
2. EEG signal processing: measure, analysis and application to brain computer interfaces
3. ECG signal analysis: measure, processing and applications to heart rate analysis
4. EEG signal processing: measure, analysis and applications to the detection of epileptic stages

Course material

[1] Kaniusas, Eugenijus, Biomedical Signals and Sensors, Linking Physiological Phenomena and Biosignals, 2012
[2] Sergio Cerutti and Carlo Marchesi, Advanced Methods of Biomedical Signal Processing, Wiley, 2011

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	14 hrs	8 hrs	0 hrs	0 hrs

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

R&D applications [APPLI]

LEAD PROFESSOR(S): Sébastien BOURGUIGNON

Objectives

This course is composed of interventions given by R&D engineers and researchers working on data analysis and processing problems in various fields of science and engineering. It aims at presenting how different kinds of information processing problems (signal, image, data analysis) are tackled in several industrial or academic research activities, using modern methodologies, in particular using the various courses and tools seen in the first two periods of the year of the DATASIM track.

Course contents

Each course takes place over one day. The morning is dedicated to a presentation of the problem encountered, its methodological obstacles and the solutions that are proposed. The afternoon is dedicated to the practical implementation of the methods developed in the first part, on real data. Provisional program (subject to changes):

ONERA: Co-design approaches for the joint acquisition and processing of data, and applications in optical imaging

RENAULT: Introduction to Data Fusion for Driving Assistance and Autonomous Vehicles

DB-SAS: Ultrasound imaging for non-destructive testing

EDF: Some case studies concerning signal and image processing problems encountered at EDF R&D.

Lagrange Laboratory (Observatory of the Côte d'Azur): Introduction to detection and some applications in Astrophysics

CNES: Space imagery: from principles to applications

Course material

Ku, Jason, et al. "Joint 3d proposal generation and object detection from view aggregation." 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2018.
S. Steyer, G. Tanzmeister and D. Wollherr, "Object tracking based on evidential dynamic occupancy grids in urban environments," 2017 IEEE Intelligent Vehicles Symposium (IV), Los Angeles, CA, 2017, pp. 1064-1070, doi: 10.1109/IVS.2017.7995855.

"Fundamentals of Statistical Signal Processing, Volume II: Detection Theory", S. Kay, Prentice Hall, 1993, ISBN-10: 013504135X

Valorge C. and al., (2012) Satellite Imagery. From acquisition principles to processing of optical images for observing the Earth, Cépadues Edition
Baghdadi N. and al., (2016). Optical Remote Sensing of Land Surface: Techniques and Methods, ISTE Press Ltd - Elsevier Inc

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	16 hrs	16 hrs	0 hrs	0 hrs	0 hrs

Audio content analysis and Information Retrieval [AUDIO]

LEAD PROFESSOR(S): Jean-François PETIOT

Objectives

This course aims to train students in:
- the principles of audio numerical representation (acoustic, encoding, processing)
- the principles of psycho acoustics (perception, cognition)
- modelling and learning of high level attributes (musical information retrieval)

Course contents

Basics of Acoustics
Representation of sounds
- spectrogramme, spectral analysis

Sound Processing and data analysis
- PCA, MDS

Perception and psychoacoustics
Auditory Scene Analysis
Source separation

Course material

Acoustique, Informatique et Musique. Outils scientifiques pour la musique. B. D'Andréa-Novel, B. Fabre, P. Jouvelot. Mines Paristech, 2012
Klapuri, A. and Davy, M. (Editors), Signal Processing Methods for Music Transcription, Springer-Verlag, New York, 2006
Auditory Scene Analysis, The Perceptual Organization of Sound, By Albert S. Bregman, MIT Press

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	12 hrs	8 hrs	0 hrs	2 hrs

ENGINEERING - OD DATASIM

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Biomedical imaging [IMBIO]

LEAD PROFESSOR(S): Diana MATEUS LAMUS

Objectives

The goal of this course is to prepare students for today's challenges and growing opportunities around computer-assisted medical procedures. The course comprises a series of lectures setting out:

- the principles behind different medical imaging techniques e.g.ultrasound, computer tomography, positron emission tomography, magnetic resonance imaging, etc.

- a selection of established methods to solve fundamental problems in medical image formation and analysis such as the segmentation, registration, and reconstruction of the images.

A core part of the course will rely on practical hands-on experience with real biomedical images.

Several of the interventions will be done by medical or industrial collaborators in the field.

Course contents

The course includes three different perspectives: Firstly, the methodological vision on the problems of acquisition and processing of medical images. Then, the vision from clinicians, physicians and industrials. Finally, the practical implementation of methodologies on some of the identified problems.

The studied imaging modalities include several among the following:
- Computer Tomography ,
- Nuclear Imaging ,
- Magnetic resonance ,
- X-Ray,
- Ultrasound

Medical Image Analysis problems and methods:
- Segmentation
- Registration
- Reconstruction

Course material

[1] N. Paragios, N. Ayache & J. Duncan. Biomedical Image Analysis: Methodologies and Applications, Springer, 2010.
[2] Jerry I. Prince: Medical imaging signals and systems textbook second edition 2014

Assessment

Collective assessment: EVC 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	14 hrs	8 hrs	0 hrs	0 hrs

Modelling and prediction of time-series [MPSET]

LEAD PROFESSOR(S): Mira RIZKALLAH

Objectives

This course concerns the advanced modeling and analysis of times series data and signals on graphs. The first part of the course focuses on experimental modeling of time series. It provides a detailed description of the time series forecasting and modeling chain from data acquisition to model validation. The second part details the graph signal processing framework starting from the graph generation to advanced signal processing on graphs.
After completing this course, the students will be able to:
- estimate the model parameters of a time series (AR, MA, ARMA, ARIMA..)
- forecast future values based on time series models with the Box-Jenkins approach.
- find a suitable graph representation of complex data.
- understand the basic concepts of graph signal processing, filtering operations, convolution, Fourier transform.
- prediction of unknown values of signals on graphs

Course contents

The course is divided in two complementary parts:
The first part is about modeling and forecasting times series:
- Time series basics : important features on a time series plot, Stationarity, Autocorrelation

Course material

- Chatfield, C. (2003). The analysis of time series: an introduction. Chapman and hall/CRC.
- Hamilton, W. L. (2020). Graph representation learning. Synthesis Lectures on Artifical Intelligence and Machine Learning, 14 (3), 1-159.
-Ortega, A. (2022). Introduction to graph signal processing. Cambridge University Press.

Assessment

Collective assessment: EVC 1 (coefficient 0.4)

Individual assessment: EVI 1 (coefficient 0.6)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	10 hrs	12 hrs	8 hrs	0 hrs	2 hrs

ENGINEERING - OD DATASIM

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Project in signal and image processing [PRTSI 2]

LEAD PROFESSOR(S): Said MOUSSAOUI

Objectives

The aim of this course is to undertake a project related to the processing of real data: audio signals, biomedical images or signals, hyperspectral images. This project begins in the autumn semester and is pursued in the spring semester.

Course contents

The projects involve the processing of real data such as:

1. Spectral data and hyperspectral images: deconvolution, decomposition and separation
2. Physiological signals: EEG, EMG for BCI and Prosthesis control
3. Audio signals: segmentation, speech recognition, content analysis
4. Medical image analysis: image segmentation, pattern recognition, etc

Course material

[1 Fundamentals of statistical signal processing - Vol I. Estimation theory. S. KAY. Prentice Hall, 1993.
System identification, theory for the user. L. LJUNG Prentice Hall, Englewood Cliffs, New Jersey, 1987 (1st ed.) - 1999 (2nd ed.).
[2] Approche bayésienne pour les problèmes inverses. J. IDIER. Traité IC2, Série traitement du signal et de l'image, Hermès, 2001.
[3] Pattern Classification. R.O. DUDA, P.E. HART, D.G.STORK, Willey 2001.
Analyse d'images, filtrage et segmentation. Sous la direction de J.P. COQUEREZ et S. PHILIPP, Masson 1995

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	2	0 hrs	0 hrs	0 hrs	48 hrs	0 hrs