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CENTRALE NANTES

ENGINEERING PROGRAMME

SPECIALISATION

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING

AUTUMN SEMESTER

Établissement public sous tutelle du
ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation

GROUPE CENTRALE

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IMAGE PROCESSING AND ANALYSIS

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION
AUTUMN SEMESTER

Professor: Diana MATEUS

Objectives

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

Course contents

Content:

- Introduction to digital images
- Image denoising and enhancement
- Restoration
- Spatial filtering
- Spectral filtering
- Morphological operators
- Geometric transformation
- Segmentation methods

Numerical implementation:

- Introduction to Python and Jupyter
- Digital image manipulation
- Filtering
- Warping
- Segmentation
- Background removal

Course material

[1] O. Faugeras, Three-dimensional computer vision: a geometric viewpoint, MIT Press, 2001.
[2] R. Horaud, O. Monga, Vision par ordinateur: outils fondamentaux, Traité des Nouvelles Technologies, Hermès, 1995.
[3] D. Forsyth, J. Ponce, Computer vision: a modern approach, Prentice Hall 2003.
[4] H. Maître (sous la direction de), Le traitement d'images, Hermès, 2003.

Keywords

Image processing. Camera calibration. Filtering. Edges. Invariants. Recognition

Links with other programmes

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	3	8 hrs	10 hrs	12 hrs	0 hrs

SCIENTIFIC COMPUTING AND NUMERICAL OPTIMIZATION

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION
AUTUMN SEMESTER

Professor: 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

Keywords

Iterative optimization, descent methods, mathematical programming

Links with other programmes

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	3	10 hrs	10 hrs	10 hrs	0 hrs

STATISTICAL DATA MODELLING AND ANALYSIS

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION

AUTUMN SEMESTER

Professor: Eric LE CARPENTIER

Objectives

This course addresses the characterization and processing of random signals by means of statistical tools. It provides the theoretical foundation used in practical problems: biomedical signalled image processing (diagnosis, tools to assist the disabled), music signal processing (recording restoration, coding), positioning systems etc.

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).
- Expectation-maximization algorithm (EM).
- Markov chains, Markov processes.
- Statistical filtering: Kalman.

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.

Keywords

Estimation theory, Signal modelling, Nonlinear filtering, Probability theory

Links with other programmes

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	3	10 hrs	12 hrs	8 hrs	0 hrs

SIGNAL REPRESENTATION AND ANALYSIS

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION
AUTUMN SEMESTER

Professor: 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 the detection of significant information in a noisy environment, extraction of characteristic features or modelling for statistical learning and classification, noise reduction or data compression by exploiting assumptions relevant to the data.
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 highlight the meaningful and useful information it contains. Different analysis tools are presented, both in their mathematical and informational foundations and in their practical numerical implementation, through application examples taken from real and simulated data analysis 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 Cohens class) representations. Lab work: comparison of different time-frequency representations; application to automatic transcription of a musical score.

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.

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

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

Keywords

Spectral analysis, Fourier transform, non-stationary signals, time-frequency analysis, wavelets, multiscale analysis, sparsity.

Links with other programmes

Statistical data modelling and analysis - Image processing and analysis - Machine learning theory and practice - Audio content analysis and Information Retrieval

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	**3**	**8 hrs**	**10 hrs**	**12 hrs**	**0 hrs**

SYSTEMS IDENTIFICATION AND SIGNAL FILTERING

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION
AUTUMN SEMESTER

Professor: Said MOUSSAOUI

Objectives

Signal filtering is a basic operation in signal processing which allows, for instance, undesired content to be deleted. The first part of this course deals with methods to design a linear filter and their application for the processing of real signals.

The second part of the course focuses on experimental signal modelling using linear models. It provides a detailed description of the signal identification chain from data acquisition to model validation.

Course contents

1. Linear filtering
   - principles of linear filtering
   - filter characterization in the frequency domain
   - analog filter synthesis
   - numerical filter synthesis (FIR, IIR)

2. System identification
   - system modelling and identification methodology
   - non-parameteric identification models and methods
   - review of linear models for system modelling (ARX, ARMAX, OE)
   - parameter estimation methods (least squares, instrumental variable, maximum likelihood)
   - continuous-time identification methods

3. Applications
   - audio signals filtering
   - use of the system identification toolbox
   - electromechanical system identification

Course material

[1] L. Ljung, System identification, Theory for the user, Prentice Hall, Englewood Cliffs, 1987
[2] . Soderstrom and P. Stoica, System identification, Prentice Hall, 1989
[3] H. Garnier and L. Wang, Identification of continuous-time models from sampled data, Springer, 2008
[4] H. Kwakernaak and R. Sivan, Modern signals and systems, Prentice Hall, Englewood Cliffs, 1991

Keywords

Dynamical system, system modelling, identification, signal filtering, filter synthesis

Links with other programmes

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	3	16 hrs	4 hrs	10 hrs	0 hrs

MACHINE LEARNING THEORY AND PRACTICE

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION
AUTUMN SEMESTER

Professor: Diana MATEUS

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 movements and their applications in the context of signals and images. We will review the most influential methods historically for unsupervised and supervised learning. The sessions will alternate between lectures, practical exercises in Python, seminars and projects. Although the techniques will be presented from a broad and general perspective, the applications will focus on images, biomedical data, and sound processing.

Course contents

- Introduction to machine learning
- Probabilistic supervised classification
- Data representation and dimensionality reduction
- Variable selection
- Linear classification
- Support Vector Machines (SVM)
- Trees and random forest algorithms
- Neural networks
- Introduction to deep learning

Course material

[1] Bishop C. : Pattern Recognition and Machine Learning. Springer, 2006.
[2] Kevin P. Murphy, "Machine Learning" MIT Press, 2013

Keywords

Machine learning, Support vector machine, Neural networks, Data analysis.

Links with other programmes

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	3	10 hrs	10 hrs	10 hrs	0 hrs

IMAGING AND INVERSE METHODS

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION
AUTUMN SEMESTER

Professor: Sébastien BOURGUIGNON

Objectives

Inverse methods are used when knowledge about an object under study is acquired indirectly, by measuring the effects of a physical phenomenon from which the causes are searched. This measurement principle is encountered in many applications in optics, acoustics, medical imaging, oceanography, astronomy or nondesctructive control of materials. Such methodology is used in most imaging methods, where a map of the physical properties inside the object is searched from measurments acquired at the exterior part of it (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, noisy and filtered by the acsuiqistion device (e.g., impulse response of a microscope or of a telescope).

This course shows basic and more advanced tools which enable one to address an inversion problem, from the definition of the direct problem (physical modeling) and general information theory elements (incomplete data, ill-posed problem, stastistical inference), the resolution principle essentially based on regularization, up to the efficient numerical computation of the solution.

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.
J. M. Mendel, Optimal Seismic Deconvolution, Academic Press, 1983.
A. C. Kak et M. Slaney, Principles of Computerized Tomographic Imaging, IEEE Press, 1988.

Keywords

Inversion, regularization, inference, deconvolution, signal and image restoration and reconstruction, tomography

Links with other programmes

Scientific computing and numerical optimization - Statistical data modelling and analysis - Signal representation and analysis - Biomedical signal analysis - Biomedical imaging - Multimodal data analysis

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	**3**	**10 hrs**	**11 hrs**	**9 hrs**	**0 hrs**

Biomedical signal analysis

Data analysis and applications in signal and image processing, Engineering programme specialisation

Autumn Semester

Professor: Eric LE CARPENTIER

Objectives

This course presents biomedical signal acquisition and processing techniques.

Course contents

The content of the course concerns 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

Keywords

Links with other programmes

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	3	10 hrs	10 hrs	10 hrs	0 hrs

PROJECT IN SIGNAL AND IMAGE PROCESSING

DATA ANALYSIS AND APPLICATIONS IN SIGNAL AND IMAGE PROCESSING, ENGINEERING PROGRAMME SPECIALISATION
AUTUMN SEMESTER

Professor: 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

Keywords

Separation, classification, optimization, signal processing, image restoration

Links with other programmes

LANGUAGE	ECTS CREDITS	LECTURES	TUTORIALS	LABO	PROJECT
French	1	0 hrs	0 hrs	0 hrs	32 hrs