Course guide
820028 - PIB - Biomedical Image Processing

Last modified: 21/01/2026

Unit in charge: Barcelona East School of Engineering
Teaching unit: 707 - ESAII - Department of Automatic Control.

Degree: BACHELOR'S DEGREE IN BIOMEDICAL ENGINEERING (Syllabus 2009). (Compulsory subject).

Academic year: 2025 **ECTS Credits:** 6.0 **Languages:** Catalan

LECTURER

Coordinating lecturer: Mata Miquel, Christian

Others: Mata Miquel, Christian
Alonso López, Joan Francesc

PRIOR SKILLS

Basic skills in linear algebra.
Basic level programming (structures if, for, while).
Abstraction skills

REQUIREMENTS

Intermediate/advanced level programming (Python)
Mastery of interactive programming environments (Google Colab, Jupyter Notebook, etc.)

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
2. Apply the techniques for analysing and interpreting biomedical signals and images.

Transversal:
1. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 3. Communicating clearly and efficiently in oral and written presentations. Adapting to audiences and communication aims by using suitable strategies and means.

TEACHING METHODOLOGY

The teaching methodology will be based on weekly theory and laboratory sessions. In the face-to-face theory sessions, faculty will introduce concepts, methods, and results of the subject through theoretical explanations and illustrative examples. Part of the theory will be based on problem-solving sessions, where the professor will guide students in completing exercises and problems related to the subject.

In laboratory sessions, students will put concepts, methods, and results into practice with faculty assistance, working directly on real biomedical images. Students will autonomously study to assimilate concepts, solve proposed exercises, and work on a group application case. Each laboratory session will culminate in an independent "Challenge" where students apply all accumulated material, solving complete biomedical image processing problems.

Finally, throughout the course, various seminars will be held by experts and clinical professionals in biomedical engineering from reference hospitals and health centers. These seminars will complement the learning of theoretical and practical concepts, providing students direct insight into the real-world applicability of acquired knowledge and demonstrating the concrete impact of this field on current biomedical challenges.

LEARNING OBJECTIVES OF THE SUBJECT

The main objective of the course is to provide students with an introductory training in biomedical image acquisition, processing, and analysis techniques. Basic concepts and traditional tools will be taught to help students acquire fundamental knowledge in this field. In the final sessions, an introduction to the use of artificial intelligence will be given, focusing on both image segmentation and classification, covering theoretical foundations as well as practical applications in clinical and research contexts. The main medical imaging modalities (X-ray, CT, MRI, ultrasound, PET, etc.) will be studied in depth, along with their specific physical and technical characteristics, clinical applicability, and inherent limitations according to medical data anonymization standards (DICOM, JPEG2000).

The course will cover advanced methods of image preprocessing and quality enhancement, including spatial and frequency filtering techniques, histogram equalization, contrast enhancement, and adaptive noise reduction to optimize diagnostic visualization. It will also explore biomedical image segmentation algorithms (thresholding, contours, clustering, region growing, or deep learning, among others), image registration (rigid and non-rigid), and anatomical structure localization, among other concepts.

This knowledge will be applied in practice through the analysis of real patient data, developing skills to solve complex biomedical engineering problems and preparing students for research and professional applications in hospitals and the medical field.

STUDY LOAD

Type	Hours	Percentage
Hours large group	45,0	30.00
Hours small group	15,0	10.00
Self study	90,0	60.00

Total learning time: 150 h

CONTENTS

Introduction and fundamentals of the digital imaging

Description:
The main fundamentals of the origin of digital imaging are explained in an introductory context, along with its mathematical morphology and structure, exploring the following concepts:

- What is a digital image? (pixel matrix, spatial and tonal resolution)
- Image representation: grayscale, color, binary
- Pixel coordinates, compression, and file formats (RAW, PNG, JPEG…)
- Grayscale images vs color images
- Main applications (biomedical, industrial, multimedia, …)

Specific objectives:
Understand the need, possibilities, and limitations of image processing, as well as the structure of a system in the biomedical field. Presentation of the course and its organization.

Related activities:
Theory class.

Full-or-part-time: 7h
Theory classes: 3h
Self study : 4h

Image acquisition methods and formats

Description:
It explains, in the context of different imaging modalities, the structure of an image processing system and the fields of application in the biomedical domain.
- X-rays
- Ultrasound
- Magnetic resonance imaging
- Other modalities
- Image formats
- Anonimization and PACS database

Specific objectives:
By the end of the session, students will be able to identify the main characteristics of biomedical imaging modalities such as X-rays, ultrasound, magnetic resonance imaging (T1/T2), and others; analyze the basic structure of image processing systems in a clinical context; recognize standard formats such as DICOM and NIfTI along with their practical applications and PACS databse; finally, relate the physical properties of each modality to the specific processing challenges associated with them.

Related activities:
Theory class activities during the practical sessions.

Full-or-part-time: 7h
Theory classes: 3h
Self study : 4h

Image manipulation

Description:
Fundamental concepts of digital image manipulation are introduced, necessary for the processing and analysis of biomedical images. Basic tools are covered to transform, enhance, and represent the information present in the image, both in grayscale and color, with special emphasis on their visual and quantitative interpretation.
- Basic concepts of image manipulation
- Histogramming and histogram analysis
- Binarization and threshold selection
- Adjustments (contrast, level curves, normalization...)
- Representation and design of color maps

Specific objectives:
By the end of the session, students will be able to understand the fundamental concepts of digital image manipulation; analyze histograms and perform binarization with threshold selection; apply image adjustments such as contrast, level curves, and normalization; and design visual representations with color maps for quantitative interpretation of biomedical images in grayscale and color.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 8h
Theory classes: 3h
Self study : 5h

Seminar I: Medical Image Acquisition by a Clinical Expert

Description:
Seminar presented by a medical imaging expert

Specific objectives:
Educational complement for achieving the knowledge explained in previous sessions and real-world applicability in the biomedical field, focused on the physical fundamentals of medical image acquisition and its variants.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 5h
Theory classes: 3h
Self study : 2h

Image Preprocessing I: Statistical Filters

Description:
Fundamental concepts of image preprocessing using statistical filters are introduced, with special attention to the effects of noise in biomedical images and reduction techniques. The properties and practical applicability of different spatial filters for noise removal while preserving essential anatomical details are compared.
- Basic concepts of noise and characterization
- Arithmetic mean filters
- Temporal filters
- Order statistics filters
- Minimum and maximum filters

Specific objectives:
By the end of the session, students will be able to identify basic noise concepts and their characteristics in biomedical images; apply arithmetic mean, temporal, order (median, percentiles), and minimum/maximum filters to reduce noise while preserving anatomical details; and compare the properties and practical applicability of these spatial filters in medical contexts.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 9h
Theory classes: 3h
Laboratory classes: 1h
Self study : 5h

Image Preprocessing II: Spatial Filters

Description:
Advanced image preprocessing using spatial filters based on 2D convolution is explained, fundamental for the frequency processing of biomedical images. The properties and applications of low-pass filters (smoothing), high-pass filters (edge detection), band-pass, and band-stop filters are detailed, with special emphasis on Gaussian filters due to their versatility in medical applications.
- Basic concepts: 2D convolution and frequency transform
- Low-pass filters (smoothing and noise reduction)
- High-pass filters (enhancement and edge detection)
- Band-pass and band-stop filters (specific frequencies)
- Gaussian filters (isotropic and anisotropic)

Specific objectives:
Understand the need for preprocessing, its different types (image transformation function and techniques), and the suitability of each according to its purpose.

Related activities:
theory class and activities during the practical sessions.

Full-or-part-time: 13h
Theory classes: 3h
Laboratory classes: 2h
Self study : 8h

Image Preprocessing III: Morphological Filters

Description:
Morphological filters for biomedical image preprocessing are introduced, based on nonlinear operations with structuring elements. The basic operations (erosion, dilation) and their combinations (opening, closing) are detailed, with practical applications in noise cleaning, separation of connected objects, and preservation of anatomical shapes in medical images.
- Basic concepts of mathematical morphology and structuring elements
- Erosion (removal of small structures, noise cleaning)
- Dilation (filling holes, connecting objects)
- Opening (noise removal while preserving shapes)
- Closing (hole filling while preserving shapes)

Specific objectives:
Understand the need for preprocessing, its different types (image transformation function and techniques), and the suitability of each according to its purpose.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 13h
Theory classes: 3h
Laboratory classes: 2h
Self study : 8h

Image segmentation I: General concepts

Description:
General concepts of image segmentation applied to biomedical images are introduced, with basic techniques to separate clinically relevant structures from the background. Thresholding methods, contour-based, region-based, and clustering methods are compared, highlighting advantages and limitations in real medical scenarios.
- Basic concepts of segmentation and quality evaluation
- Thresholding (global and adaptive)
- Contour-based segmentation (edge detection)
- Region-based segmentation (region growing)
- Clustering-based segmentation (K-means, etc.)

Specific objectives:
Based on the typology of the working images and the needs of the application, determine the type of segmentation to be used, or combination of techniques, and learn the different types of algorithms for their implementation.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 15h
Theory classes: 3h
Laboratory classes: 2h
Self study : 10h

Image Segmentation II: Feature Extraction

Description:
Feature extraction is explained as a key step in advanced biomedical image segmentation, focusing on the use of masks to analyze regional properties. Techniques for extracting geometric, intensity, and texture features are detailed, with practical applications in medical images for tissue classification and assisted diagnosis.
- Basic concepts of post-segmentation feature extraction
- Properties of mask usage (areas, perimeters, shapes)
- Extraction of geometric and intensity features
- Texture extraction methods (GLCM, Gabor filters, wavelets)
- Texture use cases in medical images (MRI, CT, mammograms)

Specific objectives:
Understand the need to extract relevant information from images for subsequent image description or scene interpretation phases. Acquire criteria to determine which information and features are relevant in each image, also considering the final application of the processing. Learn the techniques for their extraction.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 15h
Practical classes: 2h
Laboratory classes: 3h
Self study : 10h

Image registration

Description:
Medical image registration is introduced as an essential technique to align biomedical images from different modalities, times, or patients, improving comparative analysis and clinical information fusion. Basic concepts of rigid and non-rigid transformations, feature-based and intensity-based methods are detailed, with practical applications in tumor tracking, guided surgery, and image-guided therapy.
- Basic concepts: rigid, affine, and non-rigid
- Registration based on landmarks and features
- Intensity-based registration
- Elastic transformations and deformation models
- Clinical applications

Specific objectives:
Analyze the clinical needs of biomedical image registration in applications such as tumor tracking, multimodal fusion, and guided surgery, and understand the main implementation techniques: rigid/affine transformations, point-based or intensity-based registration (mutual information), and deformable models to align images from different modalities, times, or patients while preserving real anatomy.

Related activities:
Theory, class and activities during the practical sessions.

Full-or-part-time: 13h
Theory classes: 3h
Laboratory classes: 2h
Self study : 8h

Introduction to the Artificial Intelligence: Segmentation

Description:
The application of artificial intelligence to biomedical image segmentation is introduced. Differences between supervised and unsupervised algorithm types, training data, basic AI model architecture, quantitative validation, and result interpretation in clinical contexts are detailed.
- Introduction to AI in medical imaging
- Supervised vs unsupervised methods
- Data and training
- Data augmentation
- Evaluation metrics

Specific objectives:
By the end of the session, students will be able to compare traditional Machine Learning with Deep Learning in biomedical image segmentation; distinguish supervised methods (U-Net) and unsupervised methods (Random Forest); identify training data requirements (annotation, datasets like Keras, Kaggle...) and data augmentation techniques (rotations, deformations, intensity variations); and apply clinical evaluation metrics such as Dice, IoU, sensitivity, and specificity to validate models.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 20h
Theory classes: 6h
Laboratory classes: 2h
Self study : 12h

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Introduction to Artificial Intelligence: Classification

Description:
Introduces the classification of biomedical images using artificial intelligence, from basic concepts to advanced architectures. It compares classical architectures with modern transformers, citing key training techniques, optimization, and evaluation metrics for diagnostic applications in medical images. [uvadoc.uva](https://uvadoc.uva.es/handle/10324/79223?locale-attribute=en)

Main Topics
- Image classification: Basic concepts and multiclass problems.
- Classical architectures (CNN: AlexNet, VGG, ResNet). [flypix](https://flypix.ai/es/image-recognition-models-cnns/)
- Modern architectures (Vision Transformers, Swin Transformers).
[uvadoc.uva](https://uvadoc.uva.es/handle/10324/79223?locale-attribute=en)
- Training and optimization (transfer learning, fine-tuning, regularization).
[flypix](https://flypix.ai/es/image-recognition-models-cnns/)
- Evaluation metrics (accuracy, precision, recall, F1-score, ROC-AUC).
[flypix](https://flypix.ai/es/image-recognition-models-cnns/)

Specific objectives:
Understand the different types of images to choose the most suitable AI model for the classification of medical images. Additionally, the student will have a global vision of the state-of-the-art of the most current architectures in the biomedical context.
[accedacris.ulpgc](https://accedacris.ulpgc.es/bitstream/10553/130996/1/TFG%20O%20Mart%C3%ADn%20Tacoronte.pdf)

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 20h
Theory classes: 6h
Laboratory classes: 2h
Self study : 12h

Seminar II: AI application in the medical imaging

Description:
Seminar conducted by a medical image processing expert.

Specific objectives:
Educational complement to the knowledge explained in previous sessions and applicability of real use in the biomedical field focused on the use of artificial intelligence.

Related activities:
Theory class and activities during the practical sessions.

Full-or-part-time: 5h
Theory classes: 3h
Self study : 2h

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GRADING SYSTEM

The evaluation will consider the following activities:
- Laboratory sessions, including reports and the final project (LAB)
- Mid-term exam (MTE)
- End-of-term exam (ETE)

The grade for the course is obtained by the calculation 0.3*LAB + 0.3*MTE + 0.4*ETE

This course has a reassessment test, which students can undergo if they meet the requirements as per EEBE regulations: https://eebe.upc.edu/ca/estudis/avaluacio-i-permanencia

EXAMINATION RULES.

Both the midterm and the final exams are theoretical and individual, so laptops or tablets will not be needed — everything will be done on paper.

The exam will consist of two parts: the first part will include theoretical questions, and notes will not be allowed. The second part will focus on practical exercises. Only a calculator (non-programmable) may be used if necessary, without books or notes. Finally, please remember that this is a theoretical exam, so the questions will be based on the theoretical material available on ATENEA.

BIBLIOGRAPHY

Basic:
- Webb, Andrew R. Introduction to biomedical imaging. Hoboken (N.J.): Wiley, cop. 2003. ISBN 0471237663.
- González, Rafael C.; Woods, Richard E. Digital image processing. Fourth edition, Global edition. New York, NY: Pearson Education Internacional, 2018. ISBN 9781292223049|.

Complementary:
- Bankman, Isaac N.. Handbook of medical imaging : processing and analysis. San Diego [etc.]: Academic Press, cop. 2000. ISBN 0120777908.
- Rangayyan, Rangaraj M. Biomedical image analysis. Boca Raton: CRC cop, cop. 2005. ISBN 0849396956.

RESOURCES

Computer material:
- Computer Vision on Line. http://homepages.inf.ed.ac.uk/rbf/CVonline/CVentry.htm

Other resources: