Master's Department of Engineering Sciences

MSc in Automation Engineering and Robotics

Name of the unit: Advanced Image Processing

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Course code: UM5RBI20
Student workload: 12 h of lectures, 16 h of labs
Credits: 3 ECTS
Specialization tracks: ☐ ROBOT ☒ SI ☐ MeDH
Semester offered: ☐ S1 ☐ S2 ☒ S3 ☐ S4
Language of instruction: ☐ French ☒ English
Targeted audience: ☒ Engineering Sciences students ☐ Other (specify):
Localization : ☒ PMC Campus ☐ Other (specify):

Course Overview

The course unit "Advanced Image Processing" is devoted to the analysis and interpretation of digital images, which lie at the heart of computer vision. It provides students with advanced methods for processing complex images and extracting relevant information. AI approaches are used as complementary tools to strengthen these processing methods. The syllabus mainly covers 2D and 3D image segmentation (U-Net, Mask R-CNN), object detection and tracking in images and videos (YOLO, tracking), and techniques for preprocessing, data augmentation and adapting models to different image types. Students are also introduced to the analysis and presentation of recent scientific papers, together with practical work on real data. By the end of this course unit and the AI courses, students will be able to design and implement advanced image processing and analysis methods and apply them to practical problems in computer vision, imaging and visual perception systems.
Keywords: Segmentation (U-Net, Mask R-CNN), object detection and tracking (YOLO, tracking), transfer learning, domain adaptation, data augmentation, image preprocessing, computer vision, convolution, 2D/3D images, evaluation metrics (ROC, F1-score, etc.), reading scientific papers.

Prerequisites

Students should have previously acquired the following prerequisites to follow this course:

- Knowledge of mathematics, particularly calculus and probability
- Basic statistics, including understanding and using histograms
- Basic linear algebra (vectors, matrices, matrix operations)
- Basic Python programming and data manipulation
- Fundamentals of image processing (filtering, convolution, histograms)
- Basic knowledge of model evaluation (accuracy, F1-score and other standard metrics).

Intended Learning Outcomes

By the end of this course, students will be able to:

1. Analyze and represent complex 2D and 3D digital images.
2. Implement image segmentation methods (U-Net, Mask R-CNN).
3. Apply object detection and tracking techniques to images and videos (YOLO, tracking).
4. Use preprocessing and data-augmentation techniques to improve model performance.
5. Adapt existing models to new contexts through transfer learning and domain adaptation.

6. Implement image-processing pipelines using real data.
7. Analyze, critique and present scientific papers on image processing
8. Evaluate the performance of image-processing methods using relevant criteria.
9. Compare and analyze different image-processing methods

Indicative Teaching Sequence and Methods

Week	C/TD/TP*	Content	Preparation	Learn. outc.
S1	C1	Advanced segmentation (2D/3D, U-Net, Mask R-CNN)	Review of image-processing fundamentals (convolution, filtering) and linear algebra (Prerequisites 3 and 5). Introduction to Python libraries (Prerequisites 4 and 9).	
S2	C2 / TP1	Object detection: principles, YOLO and modern detection approaches / TP: advanced segmentation and applications on real data (optimization, segmentation metrics)	Review of evaluation metrics (Prerequisite 6). Practical application of the methods covered in C1.	AAV2-4, AAV8
S3	C2 / TP1	Object detection: principles, YOLO and modern detection approaches / TP: advanced segmentation and applications on real data (optimization, segmentation metrics)	Review of evaluation metrics (Prerequisite 6). Practical application of the methods covered in C1.	AAV2-4, AAV8
S4	C3	Tracking and video analysis	Understanding the fundamentals of detection (C2). Review of temporal representation and image-sequence manipulation.	AAV3, AAV6, AAV9
S5	C4 / TP2	Domain adaptation and transfer learning applied to images / TP: object tracking and complete detection-and-tracking pipelines	Basic knowledge of machine learning (Prerequisite 8). Preparation of simple datasets. Group implementation work.	AAV5-6
S6	C5	Data augmentation and advanced preprocessing	Review of histograms and statistics (Prerequisite 2). Experiments with different augmentation techniques.	AAV4, AAV8, AAV9
S7	C6 / TP3	Analysis and reading of scientific papers on image processing / Project: read and analyze a paper on segmentation, detection, data augmentation or transfer learning, and prepare an implementation and presentation. The project extends TP1 and TP2 by reusing the methods already studied.	Preliminary reading of a scientific paper. Identification of its contributions, methods and results. Project preparation	AAV6-9
S8	TP4	Project defense: final presentation and discussion	Completion of the group project. Oral presentation and discussion.	AAV6-9

* C/TD/TP respectively corresponds to lectures, tutorials and lab sessions.

Sequence of the unit:
The course unit is organized into four successive sequences:

Sequence 1: image segmentation and advanced architectures
(C1-2 + TP1 + Quiz)
Sequence 2: object detection and tracking in images and videos
(C3 + TP2 + Quiz)
Sequence 3: advanced image-processing pipelines
(C4-5 + TP3)
Transfer learning, domain adaptation and data augmentation
Sequence 4: scientific analysis and advanced practical application
(C6 + TP4 (project))

Project: students complete a project on segmentation, object detection or the design of a complete image-processing pipeline.
The project includes a literature review (state of the art), a practical implementation and an analysis of the results. It builds on the algorithms already implemented in TP1 to TP3.
The work is completed in groups of three and leads to an oral presentation, which is a central component of the assessment.

Indicative Assessment of Intended Learning Outcomes (1st session)

Week	Individ./group	In-person/remote	Type of exam	Evaluated outcomes	Scale %
S4	Individual	Remote	Quiz	AAV 1 to 3	10 %
S7	Individual	In-person	TP	AAV 1 to 9	40 %
S10	Individual	In-person	Written exam	AAV 1-9	50 %

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Session	Individ./group	In-person/remote	Type of exam	Evaluated outcomes	Scale %

Bibliographic references

- Gonzalez, R. C., Woods, R. E. Digital Image Processing, 4th Edition, Pearson, 2018
- Szeliski, R. Computer Vision: Algorithms and Applications, 2010
- Ronneberger, O., Fischer, P., Brox, T. U-Net: Convolutional Networks for Biomedical Image Segmentation, MICCAI 2015
- Rajalingappaa Shanmugamani, Deep Learning for Computer Vision: Expert Techniques, 2018
- David A. Forsyth, Jean Ponce, Compputer Vision: A modern Approach, 2011

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