Postgraduate Course
Big data for image and video signals
(MSc)

Instructor Information

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Course Information

Course Description

This course presents a selection of the most recent and relevant techniques for massively processing images and video. After the introduction of the course goals in the first lesson, a new signal sampling framework is presented in the second lesson. This sampling framework can be significantly more efficient than the famous Shannon-Nyquist sampling theorem under certain assumptions. In the third lesson, the massive processing of image and video signals is addressed, proposing big data strategies that overcome some challenges related to memory restrictions, computational cost, and the so called "curse of dimensionality". Specifically, two different approaches are described: those where the signals must be analysed and reconstructed (Compressive Sensing), and those in which the signals must be only analysed (Random projections). Next, in the fourth lesson, a selection of techniques for the efficient transmission and storing of massive image and video data is accomplished. In the fifth lesson, the techniques presented in the third lesson will be applied for the intuitive visualization of high dimensional data. Lastly, the sixth lesson will present several case studies about the practical applications in the field of computer vision and image processing.

Prerequisites

Linear algebra.

Basic optimization.

Basic probability

Image Processing and Computer Vision fundamentals.

In addition, a working knowledge of MATLAB is required.

Course Goal

Developing an understanding of the concepts and mathematical techniques that involve the acquisition, processing, transmission, storage, and visualization of massive volumes of image and video signals.

Summary of intended course outcomes

The students will understand fundamentals as well as advanced concepts in Compressive Sensing and Random Projections, the two pillars to deal with big volumes of image and video signals.

They will be able to learn a new sampling signal paradigm that can be significantly more efficient than the famous Shannon-Nyquist sampling theorem under certain assumptions. The understanding of this sampling framework will allow the students to reduce the dimension of large dimensional signals, such us collection of high resolution images or ultra-high quality video sequences, to be more tractable from a point of view of hardware resources and time. The students will also understand the prerequisites that are needed to recover the original (or a close version), along with the possible signal distortion involved in the recovery process. They will be able to apply and adapt these concepts to the life cycle of a signal: acquisition, processing, transmission, storage, and visualization. Lastly, the students will have the knowledge and insight to design and develop image and video based systems that need to deal with massive volumes of visual data. By the end of the course, students should be able to:

- Grasp the phenomenology and theory of the modern frameworks that allow to represent and recover highly dimensional image and video signals.
- Analyse, design, and implement algorithms that following the theories of Compressive sensing and Random Projections can efficiently acquire, process, transmit, store, and display big volumes of image or video signals.
- Be familiar with practical applications of image processing and computer vision that need to deal with massive volumes of data.

Syllabus

Introduction

Motivation and fundamentals.

Specific documentation will be provided by the instructors.
This chapter is based on textbooks [1, chapter 1] and [2, chapter 1].

Data acquisition

New sampling perspectives.

Specific documentation will be provided by the instructors.
This chapter is based on textbooks [1, chapter 2 and 3] and [2, chapter 3].

Data analysis

Random projections. Data dimensionality reduction.
Compressive sensing. Data reconstruction.

Specific documentation will be provided by the instructors.
This chapter is based on textbooks [1, chapter 5,6,7, and 8] and [2, chapter 2].

Data transfer and storage

Specific documentation will be provided by the instructors.
Additional reading materials in the form of academic papers will be distributed.

Data visualization
Specific documentation will be provided by the instructors.
This chapter is based on textbooks [1, chapter 11]

Case studies
Visual tracking.
Face/hand detection.
Hand gesture recognition and human activity recognition.

Specific documentation will be provided by the instructors.
This chapter is based on textbooks [1, chapter 12] and [2, chapter 4, 5, and 6].

Textbooks:

1. Y. C. Eldar and G. Kutyniok, *Compressed Sensing: Theory and Applications*. 2012.
2. V. M. Patel, *Sparse Representations and Compressive Sensing for Imaging and Vision*, vol. XXXIII, no. 2. 2013.
3. S. Foucart and H. Rauhut, *A mathematical introduction to compressive sensing*. New York, NY: Springer New York, 2013.

Recommended reading material:

1. G. Grimmett and D. Stirzaker, *Probability and Random Processes*, 3rd. ed., Oxford University Press.
2. M. Mehta , *Random Matrices*, 3rd ed., New York: Academic Press
3. LLoyd N. Trefethen and David Bau, *Numerical Linear Algebra*, III, SIAM.
4. Y. Nesterov , *Introductory Lectures on Convex Optimization: A Basic Course*, Kluwer Academic Publisher.
5. S. Mallat , *A Wavelet Tour of Signal Processing*, 3rd ed., Academic Press
6. A. Oppenheim and R. Schafer, *Discrete Time Signal Processing*, Prentice Hall.

Recommended reading papers:

1. E. Candès and M. Wakin, “An introduction to compressive sampling,” *Signal Process. Mag. IEEE*, no. March 2008, pp. 21–30, 2008.

2. D. L. Donoho, “Compressed Sensing,” pp. 1–34, 2004.
3. R. F. Marcia, “Compressed sensing for practical optical imaging systems: a tutorial,” *Opt. Eng.*, vol. 50, no. 7, p. 072601, Jul. 2011.
4. J. Romberg, “Imaging via compressive sampling,” *IEEE Signal Process. Mag.*, no. March 2008, pp. 14–20, 2008.
5. J. Haupt and R. Nowak, “Signal reconstruction from noisy random projections,” *IEEE Trans. Inf. Theory*, vol. 52, no. 9, pp. 4036–4048, 2006.
6. K. Zhang, L. Zhang, and M. Yang, “Real-time compressive tracking,” *Comput. Vision–ECCV 2012*, pp. 866–879, 2012.
7. E. J. Candès, J. Romberg, and T. Tao, “Robust uncertainty principles: Exact signal reconstruction from highly incomplete frequency information,” *IEEE Trans. Inf. Theory*, vol. 52, no. 2, pp. 489–509, 2006.
8. E. Candès and J. Romberg, “Sparsity and incoherence in compressive sampling,” *Inverse Probl.*, vol. 23, no. 3, pp. 969–985, 2007.
9. D. L. Donoho and P. B. Stark, “Uncertainty Principles and Signal Recovery,” *SIAM Journal on Applied Mathematics*, vol. 49, no. 3. pp. 906–931, 1989.

Student Assessment Criteria

Overview of selected papers (3)	10%
Final Exam	60%
Project (computer simulations)	30%

Graded projects will be assigned throughout the semester that involve the development of Matlab computer programs to get insight of the concepts seen in the theory. These projects are also considered indispensable to acquire the skill that allow the students to design and develop solution in the domain of Big Image and Video Data.