School of Advanced Technologies in Medical Sciences
Course plan

Course name: Advanced topics in digital signal processing
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Course Description:
In this course advanced statistical methods, fractal representation of the signals, stochastic differential equations, atomic representation of signals, advanced X-let transforms are introduced.

Course Aims:
The aim of this course is to help students learn advanced methodologies in processing of signals/images and provide them statistical and data adaptive tools for medical data analysis.

Assessment:
Midterm exam: 40%
Final exam: 40%
Homework: 20%

1- Fractal representation of signals

a) Overview

- Stochastic process
- Analysis of random signals (Spectral analysis, parametric models such as AR, ARMA, …)

b) Fractional order signal processing

- Fundamental concepts of fractals and fractional calculus
- Fractional stochastic process and fractional order systems
  - ✓ Fractional stochastic process
  - ✓ Long-range dependency, self-similarity, Hurst exponent, fractal dimension
- Fractional order signal processing techniques
  - ✓ Fractional order filters and operators
  - ✓ Continuous and discrete implementation of fractional order operators
  - ✓ Splines and operators
  - ✓ Fractional order Fourier transform

- ✓ Fractional order analysis of random signals (Spectral analysis, parametric models such as FARIMA …)
- ✓ Fractional Lower Order Moments and their applications

c) Stochastic differential equations (SDE)

- Fundamental concepts of SDE and Innovations approach
- Innovations for a class of Gaussian process and applications (CARMA process, Gaussian FARIMA models)
- Innovations for a class of non-Gaussian process and applications (Self-similar process, FARIMA with stable innovations)
- Innovations for modeling of images
  - ✓ General stable model
  - ✓ Mixture of stable models
  - ✓ Denoising application

2- Atomic (sparse) representation of signals

a) Fundamental concepts of sparse representation

- Different norm regularizations
- Representative algorithms
  - ✓ Greedy strategies (MP, OMP…)
  - ✓ Constrained optimization (GPSR, ADMM, BP, MCA …)
  - ✓ Proximity-algorithm based optimization (ISTA, FISTA, ALM, DALM …)

b) Fixed atoms

- Basic backgrounds
- Complex wavelets
- Xlets
  - ✓ Ridgelet
  - ✓ Curvelet
  - ✓ Bandlet
  - ✓ Shearlet
  - ✓ Laplacian pyramid …
- Quincunx wavelets
- Wavelet-based approach of fractals
  - ✓ Isotropic poly-harmonic spline wavelet
  - ✓ Fractional Laplacian Pyramid

c) Adaptive atoms

- Concepts of Dictionary learning (DL)
- Representative (unsupervised) DL methods
  - ✓ KSVD
  - ✓ Locality constrained linear coding (LLC)
  - ✓ Sparse variation dictionary learning (SVDL)
  - ✓ Dictionary learning by proximal algorithm (DLPM)
- Discriminative (supervised) DL methods
  - ✓ Discriminative KSVD (D-KSVD)
  - ✓ Label consistent KSVD (LC-KSVD)
  - ✓ Fisher discrimination dictionary learning (FDDL)

Useful Textbooks:

1- Sonka, Milan, Vaclav Hlavac, and Roger Boyle. Image processing, analysis, and machine vision. Cengage Learning, 2014.
2- Mallat, Stephane. A wavelet tour of signal processing: the sparse way. Academic press, 2008.
3- Das Saptarshi, Indranil Pan. Fractional Order Signal Processing, Introductory Concepts and Applications. Springer, 2012.
4- Gregory Wornel, Signal Processing with Fractals, a wavelet-based approach. Prentice Hall, 1995.
5- Amir Z. Averbuch, Spline and Spline Wavelet Methods with Applications to Signal and Image Processing, Springer, 2014.
6- Bogdan Dumitrescu, Dictionary Learning Algorithms and Applications, Springer, 2018.
7- Starck, Jean-Luc, Fionn Murtagh, and J. Fadili. Sparse Image and Signal Processing: Wavelets, Curvelets, Morphological Diversity. 2011.