L.EEC025 - Fundamentals of Signal Processing (FunSP)
2022/2023 – 1st semester

Lectures: **2 h/week (2 classes of ± 125 students each)**
Lab classes: **2 h/week (10 classes of ± 25 students each)**

Week-by-week Lectures/PL planning (13 weeks)

Week 1, Sept 12-16, 2022

Lecture:

- Curricular Unit presentation.
- Characterization and representation of discrete-time signals and systems.
- Linear and shift-invariant systems (LSI).
- Deterministic and discrete-time random signals.
- Special forms of the discrete convolution: the auto-correlation and the cross-correlation.

PL:

- Intro to Matlab, review of the discrete-time convolution (pencil & paper).

Week 2, Sept 19-23, 2022

Lecture:

- Introduction to the frequency-domain representation of discrete-time signals and systems.
- The discrete-time Fourier transform (DTFT). DTFT properties. DTFT transform pairs.
- The DTFT of the auto-correlation and of the cross-correlation.

PL:

- Organization of groups of 4 students for AD purposes (throughout the semester).
- Getting started with the STM32F7 Discovery kit (to be used in all FunSP Lab classes).

Week 3, Sept 26-30, 2022

Distributed Evaluation (AD)
→ peer-to-peer (P2P) assessment
→ DSP Lab

Lecture:

- Sampling and reconstruction of signals.
- Frequency-domain interpretation of sampling.
- The sampling theorem and aliasing.
- Discrete-time processing of continuous-time signals.

Illustrative problems:

- The DTFT, frequency response, DTFT properties.
- Experiments with the PDF and auto-correlation of deterministic and random signals.

PL:

- **P2P** teaching/assessment (discrete-time convolution).
- Generation on the STM32F7 kit of deterministic signals (LUT-based) and random signals. Viewing program output.

Week 4, Oct 03-07, 2022 (note: 05 Oct holiday)

Distributed Evaluation (AD)
→ VQ1 (LSI & DTFT)

Lecture:

- The direct Z-Transform. Causality and stability conditions.
- Information associated with the distribution of poles and zeros in the Z-plane.
- Z-Transform pairs.
- Characterization in the Z domain of FIR and IIR discrete-time systems (time permitting)

Illustrative problems:

- Sampling and reconstruction.

PL:

- Understanding sampling and reconstruction with the STM32F7 kit.

Week 5, Oct 10-14, 2022

Distributed Evaluation (AD)
→ peer-to-peer assessment
→ DSP Lab

Lecture:

- The inverse Z-Transform. Z-Transform properties.
- The Z-Transform of the auto/cross-correlation functions.
- Discrete equivalents of continuous-time systems (not for the 2022-2023 edition)

Illustrative problems:

- The Z-Transform.

PL:

- **P2P** teaching/assessment (Sampling and reconstruction and the frequency response of filters).
- Measuring the frequency response of a moving average filter running in real-time on the STM32F7 kit.

Week 6, Oct 17-21, 2022

Distributed Evaluation (AD)
→ VQ2 (Z-Transform)
→ peer-to-peer assessment
→ DSP Lab

Lecture:

- Characterization of LSI systems in the frequency-domain.
- Frequency-domain selectivity.
- Phase response, phase distortion and group delay.
- Inverse systems. All-pass systems.

Illustrative problems:

- The inverse Z-Transform.
- Transfer function, zero-pole analysis, and frequency response of LSI systems.

PL:

- **P2P** teaching/assessment (analysis of FIR and IIR comb filters).
- Lab on “FIR and IIR comb filters”.

Week 7, Oct 24-28, 2022

Distributed Evaluation (AD)
→ peer-to-peer assessment
→ DSP Lab

Lecture:

- Minimum-phase systems, linear-phase and maximum-phase systems.
- FIR linear-phase systems.
- Structures for the realization of IIR filters.
- Structures for the realization of FIR filters.

Illustrative problems:

- The Z-Transform in practical cases.

PL:

- **P2P** teaching/assessment (frequency-domain analysis of a minimum-phase 2nd-order IIR filter).
- Lab on "comparison between DMA-based and interrupt-based transfer of individual samples".

FEUP week (Oct 31 – Nov 04)

Week 8, Nov 07-11, 2022

Distributed Evaluation (AD)
→ VQ3 (freq-domain LSI)
→ peer-to-peer assessment
→ DSP Lab

Lecture:

- Design of IIR filters using the impulse invariance and bilinear transformation methods.
- Design of FIR filters using the window method and the MinMax optimization methods.

Illustrative problems:

- Influence of zeros and poles on the frequency response magnitude.

PL:

- **P2P** teaching/assessment (input-output relationship of a minimum-phase 2nd-order IIR filter when the input is a sinusoid).
- Lab on "test of 2nd-order IIR filters: an All-Pole and an All-Pass filter".

Week 9, Nov 14-18, 2022

Distributed Evaluation (AD)
→ peer-to-peer assessment
→ DSP Lab

Lecture:

- The Discrete Fourier Transform (DFT). Analysis and synthesis equations.
- The DFT as a frequency-domain sampling of the DTFT.
- The circular/periodic properties of the DFT.
- Relationship between the circular convolution and the linear convolution.

Illustrative problems:

- IIR filter design.

PL:

- **P2P** teaching/assessment (problems addressing FIR filter design: a discrete-time differentiator and a Hilbert transformer).
- Lab on "design, realization and test of FIR filters".

Week 10, Nov 21-25, 2022

Distributed Evaluation (AD)
→ VQ4 (IIR/FIR struc. & DFT)
→ peer-to-peer assessment
→ DSP Lab

Lecture:

- The computation of the DFT using the Fast Fourier Transform (FFT).
- The DFT-DIT and DFT-DIF algorithms.
- Programming of the FFT.
- Efficient FFT computation of real-valued signals.
- Fast FIR filtering in the frequency domain using the FFT (time permitting)
- The overlap-add and overlap-save methods (time permitting)

Illustrative problems:

- DFT and its properties.

PL:

- **P2P** teaching/assessment (sampling the DTFT and condition for the circular convolution to equal the linear convolution).
- Lab on "design and implementation of a discrete-time differentiator and Hilbert Transformer".

Week 11, Nov 28 – Dec 02, 2022 (note: 01 Dec holiday)

Lecture:

- The computation of the auto/cross-correlation using the DFT/FFT.
- The DFT as a bank of uniformly modulated filters.

Illustrative problems:

- Efficient computation of the auto/cross-correlation using the FFT.

PL:

- Lab on "6th-order IIR band-stop filter".

Week 12, Dec 05-09, 2022 (note: 08 Dec holiday)

Distributed Evaluation (AD)
→ VQ5 (still To Be Decided)

Lecture:

- Adaptive filtering (time permitting)
- Introduction to spectrum estimation using the DFT/FFT (time permitting)
- The periodogram, average spectrum, and spectrogram (time permitting)

Illustrative problems:

- TBD

PL:

- Lab on "FFT and power spectrum".

Week 13, Dec 12-16, 2022

Distributed Evaluation (AD)
→ peer-to-peer assessment
→ DSP Lab

Lecture:

- Applications of signal processing (time permitting).
- Course wrap-up and feedback.

Illustrative problems:

- Auto/cross-correlation using the FFT.

PL:

- **P2P** teaching/assessment (spectrum estimation).
- Lab on "system identification with adaptive filtering".