EL 6113 : Digital Signal Processing I Fall 2016
Section B (Selesnick)

Outline

13 Lectures + Midterm exam + Final exam

(The outline is subject to change.)

LECTURE 1
Discrete-time signals
System properties
LTI systems - convolution
    MATLAB function: conv
Connections of systems
BIBO stability condition
If time: Z-transform (definition, FIR examples)

Homework 1
From Signals packet
System classification
FIR convolution
one sided convolution
two-sided convolution
convolution as a matrix
MATLAB: plotting signals, convolution

LECTURE 2
Z-transform
    ROC
    Right-sided and left-sided signals
    Inverse Z-transform
    Partial fraction expansion
    MATLAB functions: roots, poly, residue
    Transformations of z (1/z, -z, -1/z, z^2)
Transfer functions
    Poles/zeros
Inverse systems
    non-causal systems
    stable inverses on non-minimum-phase systems
    MATLAB demo - Inverse System
If time allows:
Difference equations
    basic example
    difference equation -> transfer function
LECTURE 3
Difference equations
MATLAB function: filter
Complex poles
MATLAB demo: difference equation -> impulse response, for system with complex poles [complex_poles_demo]
Matching pole/zero and impulse responses diagrams
DC gain
Frequency response
Periodicity of frequency response
Response of LTI systems to sinusoidal inputs and frequency response evaluation of frequency response as a polynomial
MATLAB demo: frequency response
MATLAB functions: freqz, polyval
Normalized frequency
Z-transform / frequency response / unit circle
Relationships between time domain and frequency domain characteristics
poles-zeros <-> frequency response (pdf file animation)

Homework 3
From Signals packet
Difference equations
Complex poles
Frequency response
MATLAB functions: filter, freqz, polyval

LECTURE 4
DTFT
Definition
Ideal LPF / impulse response using inverse DTFT
sinc function
impulses
cosine
properties (shift, multiplication, periodicity, Parseval, etc.)
real-valued signals, symmetries
example spectra of signals (e.g., voiced and unvoiced speech)

Homework 4
frequency response
matching with pole-zero diagrams
Simple system design
   real and complex poles and zeros
DTFT problems from Oppenheim and Schafer
MATLAB: simple system design - verify them.

LECTURE 5
Simple system design (review HW 4)
   low-order systems, specified dc gain and nulls
Notch filters
   Motivation: removing 60 Hz hum, baseline drift correction
second-order recursive filter
tonal noise suppression
baseline drift correction
MATLAB demo: notch filter demo
N-point moving-average filter
   roots of unity
digital sinc function
roots of unity equally spaced on unit circle
   <-> nulls of digital sinc function equally spaced
Phase delay of system
   delay of sine through LTI system
MATLAB demo: filter delay demo

Homework 5
From Signals packet
From DSP packet
   Filters related to N-point moving average
transfer functions / filters / roots of unity
Matlab:
   baseline drift using dc notch filter
tonal noise speech filtering
higher-order notch filters

LECTURE 6
DFT
   definition
   properties
periodic and linear convolution
connection with DTFT
matching
   MATLAB functions: fft, ifft
DFT as a matrix
Circular convolution as a matrix
   relation to linear convolution
Using the DFT
  DFT to evaluate DTFT
  zero-padding
  MATLAB: fftshift
MATLAB demo: phase distortion demo
  ideal fractional-sample delay

Homework 6
DFT problems from DSP packet.
MATLAB:
  spectra of speech
  notch filter
  'anti-notch' filter

LECTURE 7
DFT/DTFT
  evaluation of spectra
  frequency leakage
Filtering
  general concepts
  ideal filters
  recursive/non-recursive filters
  approximation problem
Linear-phase FIR filters
  why linear-phase?
  the four types
  properties

Homework 7
From DSP packet
  DFT
  Filters
  Linear-phase FIR filters

LECTURE 8
FFT
  radix-2
Windows
  Standard windows
    Hamming, Hann, Blackman, Kaiser
  MATLAB functions: hamming, kaiser
FIR filter design using windows
  MATLAB functions: kaiserord, fir1
Frequency measurement using windows
FIR filter design using interpolation (DFT)
STFT (Maybe postponed to later lecture)
   definition
   parameters: frame size, hop, DFT length
   influence of parameters
   MATLAB function: specgram

Homework 8
From DSP packet
   Windows
   FIR filter design using windows
   FIR filter design by interpolation (DFT)
   STFT
Matlab: STFT

LECTURE 9
Recursive filters
   Standard types: Butterworth, Cheby1, Cheby2, Elliptic
   MATLAB demo: recursive filters demo
   MATLAB functions: butter, cheby1, cheby2, ellip
Optimal FIR filter design
   Least square linear-phase
   MATLAB function: firls
   Parks-McClellan (Remez)
   MATLAB demo: firpm demo

Homework 9
From DSP packet
   Least squares filter design
   Recursive filter design (classic methods)
Matlab:
   firls, firpm, butter, cheby1, cheby2, ellip
   low-pass filtering of noisy speech

LECTURE 10
Zero-phase filtering
   forwards-backwards filtering
   MATLAB function: filtfilt
Conversion of analog systems to digital systems
   Bilinear transformation (BLT)
   MATLAB function: bilinear
   Impulse Invariance method
Magnitude Characteristics of LTI systems
   Factorization of Desired Magnitude functions for system synthesis
All Pass Systems
Characterizations and Delay Properties
Minimum Phase Systems
   Definition
   Minimum Delay Property
   Factorization of $H(z)$ into minimum phase, all pass product

Homework 10
From DSP packet
   zero-phase filtering
Problems - Oppenheim and Schafer?
Matlab:
   compare causal IIR with zero-phase (non-causal) filtering (Matlab filter vs filtfilt)

LECTURE 11
Filter transformations
   LPF->HPF, LPF->BPF, LPF->BSF, etc.
Least squares
   overdetermined and underdetermined systems of linear equations
   differentiation wrt vectors
   normal equations
   constrained least squares
   polynomial approximation
   banded systems
   extrapolation, linear prediction
   smoothing
   deconvolution
   system identification
   interpolation

Homework 11
Least squares packet

LECTURE 12
Least squares (cont.)
   Least squares smoothing as an LTI filter
   Least squares deconvolution as an LTI filter
Fourier transforms (continuous-time)
Fourier Series and Orthogonal Functions
Sampling theorem

Homework 12
Problems - Oppenheim and Schafer..
LECTURE 13

Catch up
  if behind schedule

Special filters
  differentiators
  Hilbert transform
  fractional delay
  comb filters

Selected topics
  Convolution using overlap-add and overlap-save
  Discrete Cosine Transform (DCT)
  Stability triangle for second-order systems
  Periodogram
  Group delay
  Prony method

Homework 13
  None (last lecture)