HST582/6.555/16.456 Biomedical Signal and Image Processing HST482/6.026

Spring 2019

Time and Location
Lecture: Tuesday **and** Thursday, 9:30-11am, 56-154 (map)
Lab: Wednesday **or** Friday, 10am-1pm, 14-0637 (map)

Staff

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Overview
This course presents the fundamentals of digital signal processing with emphasis on problems in biomedical research and clinical medicine. It covers basic principles and algorithms for processing both deterministic and random signals. Topics include data acquisition, imaging, filtering, coding, feature extraction, and modeling. The focus of the course is a series of MATLAB® lab exercises that provide practical experience with cardiologic data, speech signals, and medical images. Lectures cover signal processing topics relevant to the lab exercises, as well as background on the physiological signals processed in the labs.

Values
In this class, we aim to serve a diverse community of students by creating an inclusive and supportive learning environment. Collectively, our behavior and actions should always reflect MIT's shared values of excellence, openness, integrity, and mutual respect. Moreover, a student's well-being is always our first concern; academic accomplishments should never come at the expense of one's mental or physical health.

Snow closings
In the event that MIT closes due to extreme weather conditions, please watch your email for additional instructions. In recent years we have held class via WebEx at the regularly scheduled time during snowstorms.

Materials and Website
The primary text for this class is a series of course notes that are distributed in class and posted on the class website. Optional supplementary textbooks are listed later in this document.

Access course materials and submit assignments here:
https://learning-modules.mit.edu/class/index.html?uuid=/course/6/sp19/6.555

Registered students should automatically have access. Please contact 6.555@mit.edu if you need assistance.

Grading
Final grades are determined based on:
5 lab reports – 60%
2 quizzes – 25%
5 problem sets – 10%
Class participation and effort – 5%

Problem sets are graded as follows:
4 - Few to no errors, indicating a thorough understanding of the material.
3 - Some errors, suggesting an adequate understanding of the material.
2 - Numerous errors, suggesting significant gaps in understanding of the material.
1 - Incomplete, that is, some sections not attempted.
0 - Missing or submitted late without prior arrangement.

Submitting Assignments

Problem sets and lab reports may be submitted in one of two ways:

- Paper copy turned in at the beginning of class on the due date
  OR
- File uploaded to the Stellar/Learning Modules website by 11:59pm on the due date
  - Handwritten pages must be scanned; photographs are not acceptable.
  - Electronic files should follow this naming convention:
    - LastName_FirstName_Assignment, for example: Greenberg_Julie_Lab1.pdf

Please do NOT submit both hard copy and electronic versions of the same assignment

Policy Regarding Late Assignments

Requests for extensions beyond the original due date should be made *in advance* via email to 6.555@mit.edu. In your email, please explain the circumstances necessitating the extension and propose a revised due date. Here are some examples of the types of circumstances that will generally be met with sympathy and flexibility: illness, conference travel, interview travel, multiple major assignments due in other classes on the same day.

In the absence of an approved extension, late assignments will be penalized one full point for every two days past the original deadline. (Problem sets are graded out of 4 points; labs are graded out of 10 points.)

Lab Topics

- **Filtering and Frequency Analysis of the Electrocardiogram:** Design filters to remove noise from electrocardiogram (ECG) signals and then design a system to detect life-threatening ventricular arrhythmias. The detector is tested on normal and abnormal ECG signals. (3 weeks)
- **Speech Coding**: Implement, test, and compare two speech analysis-synthesis systems that each utilize a pitch detector and a speech synthesizer based on the source-filter model of speech production. (3 weeks)
- **Image Registration**: Explore the co-registration of medical images, focusing on 2-D to 2-D (slice to slice) registration and using non-linear optimization methods to maximize various measures of image alignment. (2 weeks)
- **ECG: Blind Source Separation:** Separate fetal and maternal ECG signals using techniques based on higher-order statistical methods. Techniques include Wiener filtering, principal component analysis, and independent component analysis. (2 weeks)
- **Image Segmentation**: Process clinical MRI scans of the human brain to reduce noise, label tissue types, extract brain contours, and visualize 3-D anatomical structures. (2 weeks)

Lecture Topics

- **Data Acquisition**: Sampling in time, aliasing, interpolation, and quantization.
- **Digital Filtering**: Difference equations, FIR and IIR filters, basic properties of discrete-time systems, convolution.
- **ECG Signals**: Cardiac electrophysiology, relation of electrocardiogram (ECG) components to cardiac events, clinical applications.
- **DTFT**: Discrete-time Fourier transform and its properties. FIR filter design using windows.
- **DFT**: Discrete Fourier transform and its properties, fast Fourier transform (FFT), overlap-save algorithm, digital filtering of continuous-time signals.
- **Sampling Revisited**: Sampling and aliasing in time and frequency, spectral analysis.
- **Speech Signals**: Source-filter model of speech production, spectrographic analysis of speech.
- **Speech Coding**: Analysis-synthesis systems, channel vocoders, linear prediction of speech, linear prediction vocoders
- **Radiology for Engineers**: Overview medical imaging modalities including X-ray, fluoroscopy, ultrasound, CT, MRI, PET/nuclear medicine.
- **Image Processing**: Extension of filtering and Fourier methods to 2-D signals and systems.
- **Image Registration I and II**: Rigid and non-rigid transformations, objective functions, joint entropy, optimization methods.
- **Probability**: Random variables, probability density functions, expected value, joint probability density functions, conditional probabilities, Bayes' rule.
- **Blind source separation**: Use of principal component analysis (PCA) and independent component analysis (ICA) for filtering.
- **Random signals I**: Time averages, ensemble averages, autocorrelation functions, crosscorrelation functions.
- **Random signals II**: Random signals and linear systems, power spectra, cross spectra, Wiener filters.
- **Hypothesis Testing I**: Bayesian hypothesis testing, decision rules, likelihood ratio test, maximum likelihood decision rule, risk adjusted classifiers.
- **Hypothesis Testing II**: Non-Bayesian hypothesis testing, receiver operating characteristic (ROC) curves.
- **Advanced Image Processing Topics:** Interpolation, computed tomography, invariant features
- **Image Segmentation:** Statistical classification, morphological operators, connected components.
- **MR Physics**: Physics and signal processing for magnetic resonance imaging.
- **Diffusion Imaging Tractography for Neurosurgery**: Basics of diffusion imaging, white matter anatomy, and diffusion tractography image processing, with applications to neurosurgery.
- **Image Guided Therapy**: Survey of image processing methods used to enhance medical procedures and improve patient care.

Optional Supplementary Texts

General
- Oppenheim and Schafer (2009). Discrete-time Signal Processing, Prentice-Hall.
- Oppenheim, Willsky and Nawab (2001). Signals and Systems. Prentice Hall.
- Smith (2002). Digital Signal Processing: A Practical Guide for Engineers and Scientists, Elsevier Science & Technology Books (link).
- Karu (1995). Signals and Systems Made Ridiculously Simple. ZiZi Press.
- Buck, Daniel, and Singer (2001). Computer Explorations in Signals and Systems Using MATLAB. Prentice Hall.

Probability and Classification
- Duda, Hart and Stork (2000). Pattern classification. Wiley.
- Bishop (1996). Neural Networks for Pattern Recognition, Oxford University Press.
- Nabney (2004). Netlab: Algorithms for Pattern Recognition, Springer.
- Gubner (2006). Probability and Random Processes for Electrical and Computer Engineers, Cambridge University Press (link).

ECG Analysis
- Azuaje, Clifford, and McSharry (2006). Advanced Methods and Tools for ECG Data Analysis, Artech House (link).

Speech
- Rossing, Moore, and Wheeler (2001). The Science of Sound, Addison Wesley.
- Quatieri (2001). Discrete-Time Speech Signal Processing: Principles and Practice, Prentice Hall.

Image Processing and Medical Imaging
- Lim (1989). Two-Dimensional Signal and Image Processing, Prentice Hall.
- Gonzalez and Woods (2017). Digital Image Processing, Pearson Education.
- Epstein (2007). Introduction to the Mathematics of Medical Imaging, Society for Industrial and Applied Mathematics.
- Webb (2012). Webb's Physics of Medical Imaging, Taylor & Francis Group (link to 1988 edition).
- Westbrook, Roth, and Talbot (2011). MRI in Practice, Wiley & Sons.
- Macovski (1997). Medical Imaging Systems, Prentice Hall.

	Monday	Tuesday	Wednesday	Thursday	Friday
February	**4** *Reg Day*	**5** Lecture 1: Data Acquisition (JG)	**6** No Lab	**7** Lecture 2: ECG Signal *PS1 out*	**8** Lab 0: Intro to Matlab
	11	**12** Lecture 3: Digital Filtering (JG) *Lab 1 out*	**13** Lab 1A: ECG	**14** Lecture 4: DTFT (JG) ***PS1 due****/PS2 out*	**15** Lab 1A: ECG
	18 *Holiday*	**19** *Monday schedule*	**20** Lab 1B: ECG	**21** Lecture 5: DFT (JG) ***PS2 due****/PS3 out*	**22** Lab 1B: ECG
	25	**26** Lecture 6: Sampling Revisited (JG)	**27** Lab 1C: ECG	**28** Lecture 7: Speech Signals (JG) ***PS3 due***	**1** Lab 1C: ECG
March	**4**	**5** Lecture 8: Speech Coding (JG) ***Lab 1 due****/Lab 2 out*	**6** Lab 2A: Speech	**7** Lecture 9: Image Processing (JG) *PSX out*	**8** Lab 2A: Speech *Add Date*
	11	**12** Lecture 10: Radiology for Engineers (AT)	**13** Lab 2B: Speech	**14** Lecture 11: Image Registration I (DI) *PSX Solutions out*	**15** Lab 2B: Speech
	18	**19** Not Lecture 12: ***Quiz 1***	**20** Lab 2C: Speech	**21** Lecture 13: Image Registration II (DI)	**22** Lab 2C: Speech
	March 25-29: MIT Spring Break				
April	**1**	**2** Lecture 14: Probability (JG) ***Lab 2 due****/Lab 3 out*	**3** Lab 3A: Image Registration	**4** Lecture 15: Random Signals I (JG) *PS4 out*	**5** Lab 3A: Image Registration
	8	**9** Lecture 16: Random Signals II (JG)	**10** Lab 3B: Image Registration	**11** Lecture 17: Blind Source Separation ***PS4 due***	**12** Lab 3B: Image Registration
	15 *Holiday*	**16** *Holiday* *Lab 4 out*	**17** Lab 4A: Blind Source Separation	**18** Lecture 18: Hypothesis Testing I (JG) ***Lab 3 due/*** *PS5 out*	**19** Lab 4A: Blind Source Separation
	22	**23** Lecture 19: Hypothesis Testing II (JG)	**24** Lab 4B: Blind Source Separation	**25** Lecture 20: Advanced Image Processing Topics (SW) ***PS5 due*** *Drop Date*	**26** Lab 4B: Blind Source Separation
May	**29**	**30** Lecture 21: Image Segmentation (SW) ***Lab 4 due****/Lab 5 out*	**1** Lab 5A: Image Segmentation	**2** Lecture 22: MR Physics (BM) *PSY out*	**3** Lab 5A: Image Segmentation
	6	**7** Lecture 23: Diffusion Image Tractography (LO) *PSY Solutions out*	**8** Lab 5B: Image Segmentation	**9** Not Lecture 24: ***Quiz 2***	**10** Lab 5B: Image Segmentation
	13	**14** Lecture 25: Image Guided Therapy (TK)	**15** No Lab	**16** Lecture 26: Last class (JG) ***Lab 5 due***	