BME 50500: Image and Signal Processing in Biomedicine

Lecture 1: Introduction, Digital Signals

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Content

**Linear systems in discrete time/space**
- Impulse response, shift invariance
- Convolution
- Discrete Fourier Transform
- Sampling Theorem
- Power spectrum

**Introduction to medial imaging modalities**
- MRI
- Tomography, CT, PET
- Ultrasound

**Engineering tradeoffs**
- Sampling, aliasing
- Time and frequency resolution
- Wavelength and spatial resolution
- Aperture and resolution

**Filtering**
- Magnitude and phase response
- Filtering
- Correlation
- Template Matching

**Intensity manipulations**
- A/D conversion, linearity
- Thresholding
- Gamma correction
- Histogram equalization

**Matlab**
- Recording signals
Stuff you need

Prerequisite:
BME 405, linear systems, complex variables, Fourier transform, matlab programing.

Literature
- John L. Semmlow, Biosignal and Biomedical Image Processing: MATLAB-Based Applications, CRC Press, 2004
- Various book chapters which will announced throughout the semester.

Software
- MATLAB, available in B2, Mo-Fr 9AM -9PM.

Notes and Slides
- These slides are not a complete record of the class material. They are only a brief reminder of what was discussed in class.
- Without careful notes you will not be able to study for your exams.
Grading

60% assignments, 15% midterm exam, 25% final exam
less than 60%: F
60% or more: D
70% or more: C
80% or more: B
90% or more: A
100% or more: A+

Exams and quizzes:
• Quizzes will test reading and programming homework (they are part of the 60%).
• Final exam will test everything.

Attendance:
• 100% attendance is expected (missing quiz = 0% credit)
• Homework assignments will include data recording which will be schedules as a group.
• If you miss class do not expect homework help from the TA.
Assignments

1. MATLAB programing
   • Due one week from assignment.
   • Turn in by email prior to class!
   • May have pop quizzes on programming assignments.

2. Reading
   • Understand the subject and cover gaps.
   • May have pop quizzes on reading assignments.

3. Problems/Exercises
   • Turn in at the beginning of class.
   • Due on the next class.

4. Data recordings
   • Will schedule lab time during class hours
   • Lab will be open at additional times to complete the assignment

All written assignments must include: Name, date, course number, assignment number. Title whenever applicable. Form matters!
Getting ready - Computers

- Some of the classes will take place in the Computer Lab in B2 so we can do some hands-on programming in class.
- B2 is open from 9AM to 9PM, but a password is required to enter.
- You can do your homework in B2.
- The lab is for BME students only.
- If you have a laptop you can install MATLAB and bring it to class.
Digital signals

Digital signals are sampled and discretized
Discretization

2 gray levels

4 gray levels

8 gray levels

16 gray levels

32 gray levels

256 gray levels
Discretization

The problem with discretization is that it is a non-linear process.
Discretization

Non-linearity creates artifacts in the frequency domain.

![Graphs showing sine wave, squashing non-linearity, and squashed sine wave with power spectrum magnitudes.](image)
Discretization

Harmonic distortion explained ...

For example distortion of quadratic non-linearity leads to frequency doubling:

\[ x(t) = \sin(\omega t) \]

\[ y(t) = x^2(t) = \sin^2(\omega t) = \frac{1}{2} - \frac{1}{2} \cos(2\omega t) \]

Cubic leads triple frequencies:

\[ y(t) = \sin^3(\omega t) = \frac{3}{4} \sin(\omega t) - \frac{1}{4} \sin(3\omega t) \]

General non-linearity contains all orders according to Taylor expansion:

\[ y = f(x) = \sum_{n=0}^{\infty} \frac{1}{n!} \left[ \frac{\partial^n f(x)}{\partial x^n} \right]_{x=0} x^n \]
Sampling

If the signal is sampled every $\Delta t$ (in seconds) the sampling frequency (in Hz=s$^{-1}$) is given by:

$$f_s = \frac{1}{\Delta t}$$

For images the resolution is given by pixel size $\Delta t$ (in cm) or as pixels per cm:

$$f_s = \frac{1}{\Delta x}$$

The sampling theorem states that one has to sample a signal at least twice the frequency of the highest oscillation.

Therefore a 10Hz oscillation has to be sampled at least at every 1/20s.
Sampling

If we violate that requirement we get aliasing:

Example: \( f(x,y) = |\sin(x^2 + y^2)|. \) 720x240 pixels and amplitude scaled to [0 255] and discretized.

Sampling creates artifacts in the space (time) domain.

**Assignment 1:** Generate figures in slide 7, 8 and 13 and demonstrate with an additional figure aliasing in the time domain (generate a 10Hz sinusoid sampled at different frequencies).
Programming Assignments

- **If you copy code you will fail the course.**
- Assignments due within one week to be submitted per email to bme505@gmail.com.
- Be sure to write comments in your code to explain what you are doing.
- Submit **single executable file** called: first_last_number.m, all lower case e.g. john_smith_3.m for John's 3rd assignment. Do not submit image files or text files. Only submit executable matlab code. Your program should not generate warning. Programs that crash with an error message will receive 0 credit.
- Your program must load all required data. Assume that data files are in the current directory. All required data will be posted on the web.
- Include 'clear all, close all' at the beginning of all programs.
- Always define a sampling frequency.
- **Do not use upper case** letters for commands, e.g. Use `axis()` instead of `AXIS()`. They may work for you but they don't work for me!
- You may collaborate during your work. If you do, you **MUST** name your partner. "Similar" submission are easy to spot. Therefore, do not email each other programs, do not use USB drives to copy code. Undisclosed collaborations receive 0 credit.
- The criteria for full credit should be clear. If not, please ask in class. Do not take chances by assuming that your work is "sort of correct".