EE560: Advanced Digital Signal Processing

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Course Description

This is a general purpose, advanced DSP course designed to follow an introductory DSP course. The central theme of the course is the application of tools from linear algebra to problems in signal processing. Upon successful completion of this course you should be able to:

1) describe a range of signal processing problems using the language of bases and vector spaces,
2) use matrix decomposition to solve and analyze a range of least-squares and estimation problems,
3) efficiently compute the solutions to least-squares problems in structured/large-scale systems.

The course does not necessarily focus on a particular application; rather we will use examples from various applications to build intuition on the theory covered.

Course Topics

1. Signal representations in vector spaces
   - Introduction to discretizing signals using a basis: The Shannon-Nyquist sampling theorem
   - Linear vector spaces, linear independence, and basis expansions
   - Norms and inner products
   - Orthobases and the reproducing formula
   - Parseval’s theorem and the general discretization principle
   - Important bases: Fourier, discrete cosine, splines, wavelets
   - Signal approximation in an inner product space
   - Gram-Schmidt and the QR decomposition

2. Linear inverse problems
   - Introduction to linear inverse problems, examples
   - The singular value decomposition (SVD)
• Least-squares solutions to inverse problems and the pseudo-inverse
• Stable inversion and regularization
• Weighted least-squares and linear estimation
• Least-squares with linear constraints

3. Computing the solutions to least-squares problems
   • Cholesky and LU decomposition
   • Structured matrices: Toeplitz, diagonal+low rank, banded systems
   • Large-scale systems: Steepest descent
   • Large-scale systems: The conjugate gradient method

4. Low-rank updates for streaming solutions to least-squares problems
   • Low-rank approximation of matrices using the SVD
   • Recursive least-squares
   • The Kalman filter
   • Adaptive filtering using LMS

**Required Materials**

Below is a list of books for learning the material in this class.

- T. Kailath, A. H. Sayed, B. Hassibi: *Linear Estimation*

**Prerequisites**

An introductory course in digital signal processing covering concepts such as Fourier transforms, filtering, and sampling would be very helpful. Students should also be familiar with the fundamentals of linear algebra and should be very comfortable with the use of matrices to represent systems of equations—some existing familiarity with eigenvalues, eigenvectors, and eigenvalue decompositions will be extremely helpful. While most of the course will adopt a deterministic perspective, many of the models and algorithms we will discuss also have alternative probabilistic interpretations, and hence familiarity with the basics of probability (especially random vectors) will be useful for gaining a deeper appreciation for the material. Finally, students should also have basic MATLAB programming skills.

**Grading Policy**

Take-home Exam 30%; Project - 25%; Homework - 45% [Note that your level of participation in the course may also affect your grade, particularly if your preliminary grade falls near a borderline.]
Homework

There will be three homework assignments, some of which may include implementation exercises in MATLAB as well. In evaluating each of your problem sets, I will try to determine which of the following four categories it falls into: 1) Little evidence of any original thought or work, 2) Some attempt, but with significant gaps, 3) Good effort, but with some deficiencies in understanding, 4) Solid effort, demonstrating good understanding.

It is OK to have some collaboration on the homework with your classmates. However you must write your solutions independently, and all participants must be involved in all aspects of the joint work (hence you cannot just work on part of the homework or part of a problem in the homework and copy your friend’s solution for another part). In addition, at the top of your homework submission you must write the name of the people you have collaborated with, and specify which problems you have collaborated on. I also encourage you to have discussions with me about the problem sets during office hours. I will not accept any late homework submissions (except for the most compelling reasons), because I believe that the habit of late submissions can make it difficult for the students to keep up with the course and cause them to fall behind. While the grade you get on your homework assignments is only a minor component of your final grade, working through (often struggling at length with!) these problems is a crucial part of the learning process and will certainly have a major impact on your understanding of the material (and, in turn, your exam performances and final grade).

Exams

All exams will be take-home.

Make-up Policy

In case it is needed, there will only be one make-up exam at the end of the semester. Only health or other personal emergencies will be accepted as valid reasons to qualify you for a make-up exam.

SUCourse+

We intend to use SUCourse+ to distribute problem sets and their solutions, and as a communication medium among all of us. If you have any problems accessing the course material on SUCourse+, please let me (or IT) know as soon as possible so we can have such problems fixed.