Advanced Topics in Signal Processing

CMSE 491 and CMSE 890 (cross-listed)
Michigan State University
Fall 2022, T Th, 8:30-9:50 am EST
Engineering Building 1230

Instructor:	Saiprasad Ravishankar
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Office Hours:	Tuesdays 4-5pm EST
Office Hours Location:	EB 2507A or https://msu.zoom.us/j/93850201104

1 Course Description

This course will introduce students to advanced topics in linear algebra and vector space signal processing and their applications. The course will first review foundational topics including basics of signal processing, Fourier transforms, and probability, vector spaces, orthogonal projections, matrix inverses, least squares problems, regularization, singular value decompositions, Eckart and Young theorem, total least squares, principal component analysis, compressed sensing, dictionary learning, and recent topics in deep learning such as deep image prior. More advanced mathematical topics will include general normed vector spaces, inner product spaces, finite dimensional and infinite dimensional linear vector spaces, Hilbert spaces, projections in Hilbert spaces, linear inverse problems in general vector spaces, pseudoinverse operators, applications to extrapolation of bandlimited sequences, Hilbert space of random variables, spectral representation of discrete-time stochastic processes, linear minimum variance estimation, and Wiener filtering. Additional topics may be covered including temporal and spatial spectrum estimation, Kalman filters, and topics in machine learning.

The course will focus more on conceptual aspects and mathematical understanding and problem solving, along with some programming in Python or Matlab. The course project will help students connect the learned topics to research trends and questions. Prior programming experience is expected and knowledge of linear algebra basics, probability, Fourier transforms, signal processing, and optimization will be highly valuable.

2 Textbooks

The course materials will be based on a variety of sources including materials shared by the instructor, textbooks, and research papers. Students will find the following resources particularly useful for parts of the course.

1. Y. Bresler, S. Basu and C. Couvreur, *Hilbert Spaces and Least Squares Methods for Signal Processing*, 2021. Shared via D2L. These class notes will be referred to as BBC. **(Main Material for the class)**

2. S. Damelin and W. Miller Jr., *The Mathematics of Signal Processing* (Cambridge Texts in Applied Mathematics), Cambridge University Press, 2011. doi:10.1017/CBO9781139003896. Online: http://www-personal.umich.edu/~damelin/proofdammiller.pdf.

3. C. L. Byrne, *Signal Processing: A Mathematical Approach*, Second Edition. Chapman and Hall/CRC, 2014. https://doi.org/10.1201/b17672.

4. Michael Elad, *Sparse and Redundant Representations: From Theory to Applications in Signal and Image Processing*, Springer-Verlag New York, 2010.

5. Zhi-Pei Liang and Paul C. Lauterbur, *Principles of Magnetic Resonance Imaging: A Signal Processing Perspective*, Wiley-IEEE Press, 1999.

3 Other Required Materials

In-class or homework assignments (both mathematical/problem solving and programming type) will be a part of the learning process in this course. You are expected to have a functioning computer to complete the programming. The class strongly recommends completing these assignments in Python using Jupyter notebooks/lab. Other programming languages (for example Matlab) would also be acceptable. The course will also rely on several virtual communication tools (D2L, Zoom, Slack, etc).

4 Course Meeting Times and Locations

This class will meet in person on Tuesdays and Thursdays from 8:30am-9:50am in Engineering Building Room 1230. There will also be weekly office hours held by Dr. Ravishankar, for which Students may either come in person to Room 2507A, Engineering Building, or join via Zoom at https://msu.zoom.us/j//j/93850201104. The midterm exam will be held in late October during our class period. Final projects will be presented at the end of the semester. This is tentatively expected to be during the regular class period.

5 Course Activities

Class participation: Active class participation (led both by the instructor and by students) is critical to the success of this course. As such, students are expected to attend class every day, read any required reading materials prior to class, and engage in the in-class learning activities. A portion of the course grade is allotted for this purpose.
In-class or Homework Assignments: There will be periodic assignments (every two or three weeks) that will provide a more in-depth exploration of the materials covered in class. Students are welcome to work in teams for understanding and brainstorming these assignments, but all submitted work must be personally completed by each individual student.
Guest Lectures: There may be 1-2 guest lectures in the course, given by distinguished speakers from academia or industry.
Semester Projects: This class will have a semester project relating to the course materials that will involve studying approaches and theory in recent papers and implementing them or applying some subset of techniques learned in class to problems of personal or research interest. The project would be expected to include substantial mathematical/theoretical rigor and/or programming. Students will submit a project report and make a presentation at the end of the

semester. More details will be available near the middle of the semester. Projects must be done individually.
Study Groups: Students are encouraged to form study groups. The study groups could meet on a bi-weekly basis to review and discuss course materials and assignments.
Slack: Students and study groups are encouraged to interact with each other and with the instructors via the course's Slack channel (Slack information will be shared by the first day of instruction).

6 Other Important Information

6.1 Instructional Tools

This course will be taught in-person and may have some occasional Zoom component (e.g., possible guest lectures). The course will use Desire2Learn at (http://d2l.msu.edu) for distributing and collecting assignments and other course materials and for keeping track of grades. We will also have a course website (link will be shared by first week of classes), where important course information will be posted. The primary method of communication will be through D2L and the course Slack discussion channel. If you need an invitation to the Slack group, please contact Dr. Ravishankar and he will issue one (if you use your @msu.edu email address, you should be able to sign up at https://cmse-courses.slack.com/signup). Once you've logged into Slack, join the course channel by clicking "Channels" and then searching for the channel.

6.2 Inclusive Classroom Behavior

Respectful and responsible behavior is expected at all times, which includes not interrupting other students and not using offensive or demeaning language in our discussions. Flagrant or repeated violations of this expectation may result in ejection from the course, grade-related penalties, and/or involvement of the university Ombudsperson. In particular, behaviors that could be considered discriminatory or harassing, or unwanted sexual attention, will not be tolerated and will be immediately reported to the appropriate MSU office (which may include the MSU Police Department).

In addition, MSU welcomes a full spectrum of experiences, viewpoints, and intellectual approaches because they enrich the conversation, even as they challenge us to think differently and grow. However, we believe that expressions and actions that demean individuals or groups compromise the environment for intellectual growth and undermine the social fabric on which the community is based. These demeaning behaviors are not welcome in this course.

6.3 Academic Honesty

Intellectual integrity is the foundation of the scientific enterprise. In all instances, you must do your own work and give proper credit to all sources that you use in your reports and oral presentations – any instance of submitting another person's work, ideas, or wording as your own counts as plagiarism. This includes failing to cite any direct quotations in your homeworks/assignments, reports, or written presentations. The MSU College of Natural Science adheres to the policies of academic honesty as specified in the General Student Regulations, Protection of Scholarship and Grades, and in the all-University statement on Integrity of Scholarship and Grades, which are included in Spartan Life: Student Handbook and Resource Guide.

Students who plagiarize will receive a 0.0 in the course. In addition, University policy requires that any cheating offense, regardless of the magnitude of the infraction or punishment decided upon by the professor, be reported immediately to the dean of the student's college.

It is important to note that plagiarism in the context of this course includes, but is not limited to, directly copying another student's solutions to assignments that are expected to be completed individually (homework problems, other assignments, and exams); copying materials from online sources, textbooks, or other reference materials without citing those references in your source code or documentation, or having somebody else do your individual assignments or exams on your behalf. Any work that is done in collaboration with other students should state this explicitly, and their names as well as yours should be listed clearly. When collaborating with other students, you should still be coding/writing your own solutions to the assignments and should limit your collaboration to conceptual discussions about how one might go about solving the problems, not sharing exact solutions.

More broadly, Students should adhere to the Spartan Code of Honor academic pledge, as written by the Associated Students of Michigan State University (ASMSU): "As a Spartan, I will strive to uphold values of the highest ethical standard. I will practice honesty in my work, foster honesty in my peers, and take pride in knowing that honor is worth more than grades. I will carry these values beyond my time as a student at Michigan State University, continuing the endeavor to build personal integrity in all that I do."

7 Grading Information (Tentative)

Activity	Grade percentage
Participation/attendance*	20
Homework and other assignments	25
Midterm	15
Semester project (presentation and report)	40
Total:	100

**Attendance level must be greater than 90% to obtain the credit and participation means asking questions, etc. In case of sickness or other emergencies, please email the instructor to discuss the situation.*

Grading Scale

$4.0 \geq 90\%$
$3.5 \geq 85\%$
$3.0 \geq 80\%$
$2.5 \geq 75\%$
$2.0 \geq 70\%$
$1.5 \geq 65\%$
$1.0 \geq 60\%$
$0.0 < 60\%$