Electrical & Computer ENGINEERING — Carnegie Mellon

Course Syllabus

18-751: *Applied Stochastic Processes*
Fall, 2015

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Course Description: We introduce random processes and their applications. Throughout the course, we mainly take a discrete-time point of view, and discuss the continuous-time case when necessary. We first introduce the basic concepts of random variables, random vectors, stochastic processes, and random fields. We then introduce common random processes including the white noise, Gaussian processes, Markov processes, Poisson processes, and Markov random fields. We address moment analysis (including Karhunen- Loeve transform), the frequency-domain description, and linear systems applied to stochastic processes. We also present elements of estimation theory and optimal filtering including Wiener and Kalman filtering. Advanced topics in modern statistical signal processing such as linear prediction, linear models and spectrum estimation are discussed. 4 hrs. lec.

Number of Units: 12

Pre-requisites: 36-217 and 18-396 and senior or graduate standing.

It is strongly advised that students have a prior Signals and Systems course and a Probability course.

Course Area: Signals and Systems, Signal Processing and Communications

Class Schedule:

- *Lecture:*
  Monday & Wednesday – 9:30-11:20am PT in B23 Rm 212 (4hrs/week)

- *Labs/Recitation:*
  Friday – 9:30-11:20am PT in B23 Rm 212 (2hrs/week)

Required Textbook:

- *Probability, Random Variables, and Stochastic Processes. Papoulis, S. U. Pillai. 2001. ISBN-13: 9780071122566*

Suggested Reading:

- R. Gallager, Stochastic Processes: Theory for Applications, Draft available online
- A. Leon-Garcia, Probability and Random Processes for Electrical Engineering, 2nd ed., Prentice Hall, 1993.
- C.W. Helstrom, Probability and Stochastic Processes for Engineers, 2nd ed., Prentice Hall, 1990.

Course Webpage: www.ece.cmu.edu/~oyagan/current-course.html

Course Blackboard: To access the course blackboard from an Andrew Machine, go to the login page at: http://www.cmu.edu/blackboard. You should check the course blackboard daily for announcements and handouts.

Course Wiki:
Students are encouraged to use the ECE wiki to provide feedback about the course at: http://wiki.ece.cmu.edu/index.php.

Grading Algorithm:

30%	Homework (Best 9 out of 10)
10%	Quizzes (3 sets)
60%	Tests (3 tests, 20% each)

Tentative test schedule:
Test #1: October 9
Test #2: October 28
Test #3: December 9

Tentative Course Calendar

Date	Day	Class Activity
August/September		
8/31	Monday	Lecture 1: Review of course content. Definitions of probability experiments, sample space, event space and prob. measure, conditional probability.
9/2	Wednesday	Lecture 2: Law of total probability, Bayes' Theorem, independence of events; Events that occur "infinitely often" and "eventually", Borel-Cantelli Lemmas
9/4	Friday	Lecture 3: Definition of a random variable (discrete and continuous), distribution of a random variable (cdf and pdf), commonly used random variables

9/7	Monday	**Labor Day; No Class**
9/9	Wednesday	Lecture 4: Joint density of two or more random variables and their properties, random vectors, Conditional distribution/density, Bayes' rule for pdfs, chain rule for densities,
9/11	Friday	Lecture 5: Independence of random variables, Functions of random variables. Two functions of two random variables (and deriving their joint density).
9/14	Monday	Lecture 6: Order statistics, Mean, variance and other moments. Conditional Mean. Covariance, correlation coefficient
9/16	Wednesday	Recitation 1
9/18	Friday	Recitation 2
9/21	Monday	**No class (instructor traveling)**
9/23	Wednesday	Quiz #1
9/25	Friday	**No class (instructor traveling)**
9/28	Monday	Lecture 7: Markov inequality, Chebyshev inequality, and Chernoff bound, Joint moments, covariance matrices. Characteristic function.
9/30	Wednesday	Lecture 8: Moment Generating Function, Probability Generating Function. MMSE Estimation: definition and estimation by a constant; linear estimation.
October		
10/2	Friday	Recitation 3
10/5	Monday	Lecture 9: MMSE Estimation: unconstrained; Orthogonality principle. Convergence of sequence of real numbers
10/7	Wednesday	Lecture 10: Convergence of random variables (almost surely, r^th mean, in probability, in distribution)
10/9	Friday	**Test # 1**
10/12	Monday	Lecture 11: Law of large numbers (Weak and Strong) and Central Limit Theorem, Convergence of Binomial Distribution to Poisson.
10/14	Wednesday	Lecture 12: Bivariate Normal random variables, Multi-variate Normal Random Variables, PDF, Covariance Matrix, Characteristic Function, and properties. Transformation of Correlated Random variables into Uncorrelated ones.
10/16	Friday	Lecture 13: Discrete-time Markov Chains, definitions, examples.
10/19	Monday	Lecture 14: Time-homegenous Markov Chains, Transition probability matrix. Recurrence time, transient and recurrent states, classification of states (open, closed).
10/21	Wednesday	Lecture 15: Period of a state, stationary distributions, irreducible and reducible Markov chains, ergodicity.
10/23	Friday	Mid-Semester Break; No Class
10/26	Monday	Quiz #2 – Recitation 4
10/28	Wednesday	**Test #2**
10/30	Friday	Recitation 5 (solution of Test 2)
November		
11/2	Monday	Lecture 16: Random processes, definitions, mean, auto-correlation, and auto-covariance function. First and higher order density of random processes
11/4	Wednesday	Lecture 17: Independent and Stationary Increments Property. Gaussian random process, Brownian motion.
11/6	Friday	Recitation 6

11/9	Monday	Lecture 18: Counting processes and Poisson Process. Strict Sense Stationarity, Wide Sense Stationarity.
11/11	Wednesday	No class
11/13	Friday	Lecture 19: Cross-correlation and cross-covariance, Cyclo-stationary processes, Random processes in linear systems. WSS processes in LTI systems.
11/16	Monday	Lecture 20: Power Spectral Density, Properties, Examples
11/18	Wednesday	Lecture 21: Discrete Random Processes in LTI systems. Ergodicity, mean ergodicity, ergodicity with respect to the first and second order density function.
11/20	Friday	Recitation 7
11/23	Monday	Lecture 22: Wiener Filtering, and its general solution. Statement of the causal linear Wiener Filtering Problem, Wiener – Hopf equations. Causal functions and spectral factorization.
11/25	Wednesday	Thanksgiving Break; No Class
11/27	Friday	Thanksgiving Break; No Class
11/30	Monday	Lecture 23: Spectral factorization cont'd. Multiplicative decomposition. Solution of the causal Wiener Filtering problem for rational PSD's.
December		
12/2	Wednesday	Lecture 24: Selected topics
12/4	Friday	Quiz 3 & Recitation 8
12/7	Monday	Lecture 25: Review
12/9	Wednesday	**Test # 3**
12/11	Friday	Last day of class
12/14	Monday	*Final exams*
12/18	Friday	*Final Exams*

Education Objectives (Relationship of Course to Program Outcomes)
*** Keep only those that apply and append a brief description of what is done in the course do address each outcome*

(a) an ability to apply knowledge of mathematics, science, and engineering: <<description>>

(b) an ability to design and conduct experiments, as well as to analyze and interpret data: <<description>>

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability: <<description>>

(d) an ability to function on multi-disciplinary teams: <<description>>

(e) an ability to identify, formulate, and solve engineering problems: <<description>>

(f) an understanding of professional and ethical responsibility: <<description>>

(g) an ability to communicate effectively: <<description>>

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context: <<description>>

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues: <<description>>

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice: <<description>>

ECE Academic Integrity Policy (http://www.ece.cmu.edu/programs-admissions/masters/academic-integrity.html**):**

The Department of Electrical and Computer Engineering adheres to the academic integrity policies set forth by Carnegie Mellon University and by the College of Engineering. ECE students should review fully and carefully Carnegie Mellon University's policies regarding Cheating and Plagiarism; Undergraduate Academic Discipline; and Graduate Academic Discipline. ECE graduate student should further review the Penalties for Graduate Student Academic Integrity Violations in CIT outlined in the CIT Policy on Graduate Student Academic Integrity Violations. In addition to the above university and college-level policies, it is ECE's policy that an ECE graduate student may not drop a course in which a disciplinary action is assessed or pending without the course instructor's explicit approval. Further, an ECE course instructor may set his/her own course-specific academic integrity policies that do not conflict with university and college-level policies; course-specific policies should be made available to the students in writing in the first week of class.

This policy applies, in all respects, to this course.

CMU Academic Integrity Policy (http://www.cmu.edu/academic-integrity/index.html**):**

In the midst of self exploration, the high demands of a challenging academic environment can create situations where some students have difficulty exercising good judgment. Academic challenges can provide many opportunities for high standards to evolve if students actively reflect on these challenges and if the community supports discussions to aid in this process. It is the responsibility of the entire community to establish and maintain the integrity of our university.

This site is offered as a comprehensive and accessible resource compiling and organizing the multitude of information pertaining to academic integrity that is available from across the university. These pages include practical information concerning policies, protocols and best practices as well as articulations of the institutional values from which the policies and protocols grew. The Carnegie Mellon Code, while not formally an honor code, serves as the foundation of these values and frames the expectations of our community with regard to personal integrity.

The Carnegie Mellon Code

Students at Carnegie Mellon, because they are members of an academic community dedicated to the achievement of excellence, are expected to meet the highest standards of personal, ethical and moral conduct possible.

These standards require personal integrity, a commitment to honesty without compromise, as well as truth without equivocation and a willingness to place the good of the community above the good of the self. Obligations once undertaken must be met, commitments kept.

As members of the Carnegie Mellon community, individuals are expected to uphold the standards of the community in addition to holding others accountable for said standards. It is rare that the life of a student in an academic community can be so private that it will not affect the community as a whole or that the above standards do not apply.

The discovery, advancement and communication of knowledge are not possible without a commitment to these standards. Creativity cannot exist without acknowledgment of the creativity of others. New knowledge cannot be developed without credit for prior knowledge. Without the ability to trust that these principles will be observed, an academic community cannot exist.

The commitment of its faculty, staff and students to these standards contributes to the high respect in which the Carnegie Mellon degree is held. Students must not destroy that respect by their failure to meet these standards. Students who cannot meet them should voluntarily withdraw from the university.

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Cheating (http://www.cmu.edu/academic-integrity/cheating/index.html) states the following:

According to the University Policy on Academic Integrity, cheating "occurs when a student avails her/himself of an unfair or disallowed advantage which includes but is not limited to:

- Theft of or unauthorized access to an exam, answer key or other graded work from previous course offerings.
- Use of an alternate, stand-in or proxy during an examination.

- Copying from the examination or work of another person or source.
- Submission or use of falsified data.
- Using false statements to obtain additional time or other accommodation.
- Falsification of academic credentials."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Plagiarism (http://www.cmu.edu/academic-integrity/plagiarism/index.html) states the following:

According to the University Policy on Academic Integrity, plagiarism "is defined as the use of work or concepts contributed by other individuals without proper attribution or citation. Unique ideas or materials taken from another source for either written or oral use must be fully acknowledged in academic work to be graded. Examples of sources expected to be referenced include but are not limited to:

- Text, either written or spoken, quoted directly or paraphrased.
- Graphic elements.
- Passages of music, existing either as sound or as notation.
- Mathematical proofs.
- Scientific data.
- Concepts or material derived from the work, published or unpublished, of another person."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Unauthorized Assistance (http://www.cmu.edu/academic-integrity/collaboration/index.html) states the following:

According to the University Policy on Academic Integrity, unauthorized assistance "refers to the use of sources of support that have not been specifically authorized in this policy statement or by the course instructor(s) in the completion of academic work to be graded. Such sources of support may include but are not limited to advice or help provided by another individual, published or unpublished written sources, and electronic sources. Examples of unauthorized assistance include but are not limited to:

- Collaboration on any assignment beyond the standards authorized by this policy statement and the course instructor(s).
- Submission of work completed or edited in whole or in part by another person.
- Supplying or communicating unauthorized information or materials, including graded work and answer keys from previous course offerings, in any way to another student.
- Use of unauthorized information or materials, including graded work and answer keys from previous course offerings.
- Use of unauthorized devices.

- Submission for credit of previously completed graded work in a second course without first obtaining permission from the instructor(s) of the second course. In the case of concurrent courses, permission to submit the same work for credit in two courses must be obtained from the instructors of both courses."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Research Misconduct (http://www.cmu.edu/academic-integrity/research/index.html) states the following:

According to the University Policy For Handling Alleged Misconduct In Research, "Carnegie Mellon University is responsible for the integrity of research conducted at the university. As a community of scholars, in which truth and integrity are fundamental, the university must establish procedures for the investigation of allegations of misconduct of research with due care to protect the rights of those accused, those making the allegations, and the university. Furthermore, federal regulations require the university to have explicit procedures for addressing incidents in which there are allegations of misconduct in research."

The policy goes on to note that "misconduct means:

- fabrication, falsification, plagiarism, or other serious deviation from accepted practices in proposing, carrying out, or reporting results from research;
- material failure to comply with Federal requirements for the protection of researchers, human subjects, or the public or for ensuring the welfare of laboratory animals; or
- failure to meet other material legal requirements governing research."

"To be deemed misconduct for the purposes of this policy, a 'material failure to comply with Federal requirements' or a 'failure to meet other material legal requirements' must be intentional or grossly negligent."

To become familiar with the expectations around the responsible conduct of research, please review the guidelines for Research Ethics published by the Office of Research Integrity and Compliance.

This policy applies, in all respects, to this course.