First Course Handout

EE 623A Detection and Estimation Theory
Spring Semester, AY 2021-22
Department of Electrical Engineering
Indian Institute of Technology Kanpur
https://www.iitk.ac.in/mwn/EE623A_S22/index.html

1. Objectives:

All lectures will be conducted live via zoom. Course will also have black-board style teaching, assignments, live problem discussion/ MATLAB coding sessions. First lecture will be held 6th January, 2021.

The course will have both theoretical and practical aspects. It aims to explain the fundamental principles and insights pertaining to signal estimation and detection followed by their applications in various areas such as **signal processing**, **wireless communication**, **image processing** and also **machine learning**. As part of the course, detailed analytical models will be presented for various frameworks followed by detailed performance analysis. The course intends to cover several key concepts such as *Maximum Likelihood (ML), Minimum Mean Squared Error (MMSE), Linear MMSE (LMMSE), Kalman Filter, Neyman Pearson (NP) Criterion, Optimal Detection, Classification, Bayesian Detection and Generalized Likelihood Ratio Test.* Various applications will be covered such as **Linear Regression, Channel Estimation**, **MIMO, Auto-Regressive modeling, Recommender systems, Unsupervised Learning, EM Algorithm etc**. Finally, students working in groups of two are expected to prepare a term paper that will focus on an in-depth study and analysis of any cutting edge application of the concepts of estimation/ detection in any related area such as signal processing, wireless communication, image processing and also machine learning.

2. Prerequisites:

- EE320/ EE200 for B.Tech students in EE department.
- No prerequisite for M.Tech/ Ph.D. students enrolled in EE Department.
- Instructor consent for all other students.

Students are expected to be familiar with basic concepts of

- Probability, Random Variables and Random Processes
- Linear Algebra, Properties of Matrices etc.
- Calculus, differentiation, integration

3. Course Contents:

Maximum Likelihood (ML) Estimation	**No. of Lectures**
Observation model, Likelihood Function, Vector parameter	1
Least Squares problem, Pseudo-inverse and Maximum Likelihood (ML) Estimate, Application in Machine Learning: Linear Regression	1
Properties of ML estimate – Mean and Covariance	1
ML estimate with Colored Noise	1
Mean and covariance of estimate with colored noise	1
Application of Least Squares: Channel Estimation in Wireless Systems	1
Least norm estimation – Solution and optimality	1
Application of Least Norm solution: Beamforming in 4G/ 5G wireless systems	1
Cramer Rao Lower Bound	
Concept of Cramer-Rao (CRB) for Parameter Estimation	1
Derivation and properties of CRB	1
Bayesian Estimation	
Bayesian estimation philosopy and MMSE Estimator	1
Conditional Gaussian PDF and MMSE Estimation for Gaussian vectors	1

Principle of LMMSE estimation and Derivation of the LMMSE estimator	1
LMMSE estimator and Linear signal Model: Application in MIMO Wireless Systems	2
Kalman Filter	
Introduction to Online Estimation	1
Online Estimation for Deterministic Parameter	1
Online estimation for Random Parameter Vector: Kalman Filter and application in tracking Application of Kaman Filter for Robotics	2
Cramer-Rao Bound for Kalman Filter	1
Iterative Maximum-Likelihood (ML)	
Expection-Maximization (EM) algorithm	1
Application of EM: Unsupervised learning – Probabilistic clustering	1
Application of EM: Sparse Bayesian Learning	1
Compressive Sensing	
Sparse estimation and sparse signal recovery: Application in Image/ Video Processing	1
Orthogonal Matching Pursuit (OMP) and Simultaneous Orthogonal Matching Pursuit (SOMP) for Sparse Regression	2
Signal Detection/ Classification	
Concept of Hypothesis testing, Detection and False Alarm	1
Optimal detection and Neyman Pearson criterion	2
Bayes classifier and Minimum Probability of Error	1
Detection with Known Signals	
Introduction, signal model and Principle of Matched filter	2

Performance of matched filter, Probability of detection, false alarm and probability of error	2
Application: Gaussian classifier for Machine Learning	1
Matched filter with Colored Noise and performance	1
Detection of Random Signals	
System model with Random signals	1
Estimator correlator, performance for finite and large number of samples	1
Application: Cognitive Radio Spectrum Sensing	1
Detection/ Classification with unknown parameters, Generalized Likelihood Ratio Test (GLRT) principle	2

4. Special Emphasis:

- Maximum-Likelihood (ML) Principle
- Minimum Mean Square Error (MMSE)
- Kalman Filter
- Neyman-Pearson Criterion
- Applications: Signal Processing, Machine Learning, Wireless Comm.

5. Lecture, Tutorial & Lab Schedule & Venue:

- Venue: Will be conducted online via Zoom
- Timings: To be decided after consulting students

6. Office Hours or, recommended mode of contact beyond formal contact hours:

- Saturday 12 noon via skype.
- Students can also contact both instructor as well as TAs via e-mail.

7. Evaluation Components & Policies:

	Weightage
Assignments (Theory + MATLAB)	15%

Mid-Sem	20%
Quiz-I	10%
Quiz-II	10%
Term Paper	10%
End-Sem	25%
Attendance Minimum 75% attendance	10%

Exam/ Assignment/ Term Paper Policy:

If a student misses any one or more of Quiz-I/ Quiz-II/ Mid-sem, marks will be pro-rated based on remaining ones, if valid reason is provided along with supporting documents. If a student misses the end-sem exam, he/ she can apply to DOAA for makeup examination. Assignment solution or term paper submission is due by 12 Noon of respective due date. 15% Marks will be deducted for late submission. No makeup or prorating will be done for missed assignment submissions or term paper.

8. Course Policies: Attendance, Honesty Practices, Withdrawal (within the limits of DOAA Guidelines)

Attendance Policy: Minimum 75% attendance is required to score the 10% marks specified for attendance as per **Evaluation Policies** in Section 7. Attendance will be recorded in every session.

Instructor created notes will NOT be disseminated. Each student is expected to take notes and keep a record. All participants MUST keep their video feed ON during the course to monitor attendance and participation. Further, recorded video lectures will be available with a one week delay and available for one week. Exceptions can be made when a student is not able to attend a lecture due to genuine reasons. In such a case, lecture can be made available immediately but only for a day or two.

Students are expected to observe a **personal code of honesty** in submission of assignment solutions and term paper. This will be based on honor code. Term papers will be checked by software to detect any plagiarism. 25% marks will be deducted for plagiarism.

9. Books & References: Properly Formatted along with listing of possible internet sources.

Text Book	
Fundamentals of Statistical Signal Processing: Estimation Theory	Steven M. Kay
Fundamentals of Statistical Signal Processing: Detection Theory	Steven M. Kay

10. Instructor and TA Information

Instructor	
Prof. Aditya K. Jagannatham	ACES 205D Mailbox on 2nd floor ACES Building. e-mail: adityaj@iitk.ac.in Ph: 7494
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