Advanced Control Systems
Detection, Estimation, and Filtering

Graduate Course on the
MEng PhD Program
Spring 2012/2013

Instructor:
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Objectives:

• Motivation for estimation, detection, filtering, and identification in stochastic signal processing

• Methodologies on design and synthesis of optimal estimation algorithms

• Characterization of estimators and tools to study their performance

• To provide an overview in all principal estimation approaches and the rationale for choosing a particular technique

Both for parameter and state estimation,

always on the presence of stochastic disturbances

In RADAR (Radio Detection and Ranging), SONAR (sound navigation and ranging), speech, image, sensor networks, geo-physical sciences,…

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Pre-requisites:

• Random Variables and Stochastic Processes

Joint, marginal, and conditional probability density functions: Gaussian / normal distributions; Moments of random variables (mean and variance); Wide-sense stationary processes; Correlation and covariance; Power spectral density;

• Linear Algebra

Vectors: orthogonality, linear independence, inner product; norms;

Matrices: eigenvectors, rank, inverse, and pseudo-inverse;

• Linear Systems

LTIS and LTVs; ODEs and solutions; Response of linear systems; Transition matrix; Observability and controlability; Lyapunov stability.

The implementation of solutions for problems require the use of ***MATLAB*** and ***Simulink***.

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Syllabus:

Classical Estimation Theory

Chap. 1 - ***Motivation for Estimation in Stochastic Signal Processing*** [1/2 week]

Motivating examples of signals and systems in detection and estimation problems;

Chap. 2 - ***Minimum Variance Unbiased Estimation*** [1 week]

Unbiased estimators; Minimum Variance Criterion; Extension to vector parameters; Efficiency of estimators;

Chap. 3 - ***Cramer-Rao Lower Bound*** [1 week]
Estimator accuracy; Cramer-Rao lower bound (CRLB); CRLB for signals in white Gaussian noise; Examples;

continues…

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Syllabus (cont.):

Chap. 4 - ***Linear Models in the Presence of Stochastic Signals*** [1/2 week]

Stationary and transient analysis; White Gaussian noise and linear systems; Examples; Sufficient Statistics; Relation with MVU Estimators;

Chap. 5 - ***Best Linear Unbiased Estimators*** [1 week]

Definition of BLUE estimators; White Gaussian noise and bandlimited systems; Examples; Generalized minimum variance unbiased estimation;

Chap. 6 - ***Maximum Likelihood Estimation*** [1 week]

The maximum likelihood estimator; Properties of the ML estimators; Solution for ML estimation; Examples; Monte-Carlo methods;

Chap. 7 - ***Least Squares*** [1 week]

The least squares approach; Linear and nonlinear least squares; Geometric interpretation; Constrained least squares; Examples;

continues…

Syllabus (cont.):

Bayesian Estimation Theory

Chap. 8 – ***Bayesian Estimation*** [1/2 week]

Philosophy and estimator design; Prior knowledge; Bayesian linear model; Bayesian estimation on the presence of Gaussian pdfs; Minimum Mean Square Estimators;

Chap. 9 – ***Wiener Filtering*** [1/2 week]

The Wiener filter problem; Causal and non-causal solutions; Complementary filters;

Chap. 10 – ***Kalman Filtering*** [2 weeks]

Optimal estimator in the presence of white Gaussian noise – the Kalman filter; Stability, convergence and robustness for LTV and LTI systems; Kalman and Wiener filters; Optimal smoothers; Examples; Extended Kalman Filters;

continues…

Syllabus (cont.):

Advanced Estimation Topics

Chap. 11 – ***Multiple Model Adaptive Estimation*** [1 week]

Joint system identification and parameter/state estimation using multiple models.

Chap. 12 – ***Optimal Smoothing*** [1 week]

Fixed point, fixed interval, and fixed lag smoothers.

Chap. 13 – ***Advanced Topics*** [2 weeks]

To be detailed later, e.g. Positioning and navigation systems; Failure detection and isolation; Multiple model adaptive estimation; Discretization; Missing data estimation; Outlier detection and removal; Feature based estimation; Principal component analysis; Nonlinear signal processing; Compressive sensing;…

End.

Grading:

- Five problem sets (50%)

  Due dates: weeks of 25-03, 08-04, 22-04, 06-05, 06-20 and 03-06 (tentative).

and

- Term paper (50%)

  Topic selected randomly by the student. Worked jointly by the faculty/student.
  To be completed in the final 3-4 weeks, i.e. week of 5-07.

or

- Final exam (50%)

  Week of 15-07.

Classes:

Tuesdays:	16h00 – 17h30, room C11
Thurdays:	16h00 – 17h30, room P9

To discuss issues: i) e-mail, ii) phone, or iii) schedule an interview.

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Bibliography:

Main references

• Steven M. Kay, ***Fundamentals of Statistical Signal Processing: Estimation Theory,*** *Vol. I*, Prentice Hall Signal Processing Series, 1993.

• A. Gelb, ***Applied Optimal Estimation,*** MIT Press, 1974.

Complementary reading

• Steven M. Kay, ***Fundamentals of Statistical Signal Processing: Detection Theory, Vol. II,*** Prentice Hall Signal Processing Series, 1998.

• Harry L. Van Trees, ***Detection, Estimation, and Modulation Theory, Parts I to IV,*** John Wiley, 2001.

• Athanasios Papoulis and S. Unnikrishna Pillai, ***Probability, Random Variables and Stochastic Processes,*** McGraw Hill, 2001.

• Robert Brown and Patrick Hwang, ***Introduction to Random Signals and Applied Kalman Filtering,*** John Wiley, 1997.

• Gonzalo Arce, ***Nonlinear Signal Processing: A Statistical Approach,*** John Wiley, 2005.