

Estimation, Detection, and Identification ***CMU 18752***

***Graduate Course on the
CMU/Portugal ECE PhD Program
Spring 2008/2009***

***Instructor:
Prof. Paulo Jorge Oliveira
pjcro @ isr.ist.utl.pt
Phone: +351 21 8418053 ou 2053 (inside IST)***



Detection, Estimation, and Filtering

***Graduate Course on the
CMU/Portugal ECE PhD Program
Spring 2008/2009***

***Instructor:
Prof. Paulo Jorge Oliveira
pjcro @ isr.ist.utl.pt
Phone: +351 21 8418053 ou 2053 (inside IST)***



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,...

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 controllability; Lyapunov stability.

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

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...

Syllabus (cont.):

Chap. 4 - **Linear Models in the Presence of Stochastic Signals** [1 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;

Syllabus (cont.):

Bayesian Estimation Theory

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

Neyman-Pearson Theorem; Binary hypotheses testing; ROC; Examples;

Chap. 12 – **Identification** [1 week]

Classic Identification methods; Prediction Error Method for State Space Models; Stochastic Realization; Subspace Methods of System Identification;

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 23-03, 06-04, 27-04, 18-05, 08-06 (proposal).

and

- Term paper (50%)

Topic jointly selected by the student and the faculty.

To be completed in the final 3-4 weeks, i.e. week of 15-06.

or

- Final exam (50%)

Week of 15-06.

Classes:

Tuesdays: 15h30 - 17h00

Thursdays: 15h30 - 17h00

Room: E5

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

Bibliography:

Main references

- Steven M. Kay, ***Fundamentals of Statistical Signal Processing: Estimation Theory, Vol. I***, Prentice Hall Signal Processing Series, 1993.
- Steven M. Kay, ***Fundamentals of Statistical Signal Processing: Detection Theory, Vol. II***, Prentice Hall Signal Processing Series, 1998.

Complementary reading

- 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.