Engineering Tripos Part IIB, 4F7: Statistical Signal Analysis, 2017-18

Module Leader
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Lecturer
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Timing and Structure
Michaelmas term. 16 lectures (including examples classes). Assessment: 100% exam

Prerequisites
3F3; Useful 3F1 and 3F8

Aims
The aims of the course are to:

- Continue the study of statistical signal processing from the basics studied in 3F3.
- Introduce the fundamental concepts and methods of adaptive filtering.
- Introduce time-series models, in particular Hidden Markov Models; understand their role in applications of signal processing; develop techniques for estimating hidden signals from noisy observations.
- Develop techniques for calibrating statistical time-series models for real data.

Objectives
As specific objectives, by the end of the course students should be able to:

- Understand the theory and objectives of optimal filtering in an adaptive setting.
- Recognise and describe the classes of problem where adaptive filtering might be applied.
- Describe the implementation of the Least Mean Square and its variants, and understand their convergence properties.
- Understand the basic principles of Kalman filtering and filtering for hidden Markov models.
- Understand the principles of Sequential Importance Sampling with Resampling, also known as particle filtering, for inference in hidden Markov models.
- Understand Maximum Likelihood estimation for model calibration and its implementation.
- Formulate signal processing tasks in a model-based framework, and to estimate the model parameters.

Content
The first aim of the course is to introduce the fundamental concepts and methods of adaptive linear filtering, i.e. filters that are linear functions of the data, which attempt to adapt their parameters automatically on-line to the data at hand. Examples of this are echo cancellation in telephony or background noise cancellation. (This part of the course is an extension of the basic filter design material combined with the optimal filtering material from 3F3.) Optimality of these techniques require that the data generating processes satisfy certain stationarity assumptions. Modern filtering theory will then be introduced through state-space models that do not require
any stationarity assumptions. State-space mode are thus far more general and more widely applicable to real data settings. An even more general model is the hidden Markov model which will be studied in detail. Inference aims for the hidden Markov model will be defined and exact computation of the probability laws will be addressed. In many applications though exact computation is not possible and the most successful technique to date that addresses this problem is a Monte Carlo method called sequential importance sampling with resampling, also known as particle filtering. The particle filter will be derived and applied to both inference and model calibration for time-series data.

- Optimal linear filtering: the least mean square algorithm and its variants; recursive least squares; exemplar problems in signal processing.
- Introduction to state-space models and the recursive optimal linear filtering; the Kalman filter.
- Introduction to hidden Markov models: definition; inference aims; exact computation of the filter.
- Importance sampling: introduction; weight degeneracy.
- Sequential importance sampling and resampling (also known as the particle filter): application to hidden Markov models; filtering; smoothing.
- Calibrating hidden Markov models: maximum likelihood estimation and its implementation
- Exemplar problems in Signal Processing

Booklists

Please see the Booklist for Group F Courses [2] for references for this module.

Examination Guidelines

Please refer to Form & conduct of the examinations [3].

UK-SPEC

The UK Standard for Professional Engineering Competence (UK-SPEC) [4] describes the requirements that have to be met in order to become a Chartered Engineer, and gives examples of ways of doing this.

UK-SPEC is published by the Engineering Council on behalf of the UK engineering profession. The standard has been developed, and is regularly updated, by panels representing professional engineering institutions, employers and engineering educators. Of particular relevance here is the 'Accreditation of Higher Education Programmes' (AHEP) document [5] which sets out the standard for degree accreditation.

The Output Standards Matrices [6] indicate where each of the Output Criteria as specified in the AHEP 3rd edition document is addressed within the Engineering and Manufacturing Engineering Triposes.

Last modified: 16/09/2017 11:16

Source URL (modified on 16-09-17): http://teaching.eng.cam.ac.uk/content/engineering-tripos-part-iib-4f7-statistical-signal-analysis-2017-18

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