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

Module Leader

Dr S.S. Singh [1]

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, aslo known as particle filtering, for inference in hidden Markov models.
- Undertand 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
- Examples Papers

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

This syllabus contributes to the following areas of the UK-SPEC [4] standard:

Toggle display of UK-SPEC areas.

GT1

Develop transferable skills that will be of value in a wide range of situations. These are exemplified by the Qualifications and Curriculum Authority Higher Level Key Skills and include problem solving, communication, and working with others, as well as the effective use of general IT facilities and information retrieval skills. They also include planning self-learning and improving performance, as the foundation for lifelong learning/CPD.

IA1

Apply appropriate quantitative science and engineering tools to the analysis of problems.

IA2

Demonstrate creative and innovative ability in the synthesis of solutions and in formulating designs.

KU1

Demonstrate knowledge and understanding of essential facts, concepts, theories and principles of their engineering discipline, and its underpinning science and mathematics.

KU2

Have an appreciation of the wider multidisciplinary engineering context and its underlying principles.

E1

Ability to use fundamental knowledge to investigate new and emerging technologies.

E2

Ability to extract data pertinent to an unfamiliar problem, and apply its solution using computer based engineering tools when appropriate.

E3

Ability to apply mathematical and computer based models for solving problems in engineering, and the ability to assess the limitations of particular cases.

E4

Understanding of and ability to apply a systems approach to engineering problems.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

P3

Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc).

P8

Ability to apply engineering techniques taking account of a range of commercial and industrial constraints.

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

US2

A comprehensive knowledge and understanding of mathematical and computer models relevant to the engineering discipline, and an appreciation of their limitations.

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