Engineering Tripos Part IIA, 3F3: Statistical Signal Processing, 2024-25

Module Leader

Prof S Godsill [1]

Lecturers

Prof S. J. Godsill, Dr G Cantwell

Lab Leader

Dr G Cantwell [2]

Timing and Structure

Michaelmas term. 16 lectures.

Aims

The aims of the course are to:

- Study more advanced probability theory, leading into random process theory.
- Study random process theory and focus on discrete time methods.
- Introduce inferential methodology, including maximum likelihood and Bayesian procedures, and examples drawn from signal processing. Objectives

Objectives

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

- By the end of the course students should be familiar with the fundamental concepts of statistical signal processing, including random processes, probability, estimation and inference.

Content

Lectures 1-8: Advanced Probability and Random Processes

- **Probability and random variables**
    - Sample space, events, probability measure, axioms.
    - Conditional probability, probability chain rule, independence, Bayes rule.
    - Random variables (discrete and continuous), probability mass function (pmf), probability density function (pdf), cumulative distribution function, transformation of random variables.

    - Bivariate: conditional pmf, conditional pdf, expectation, conditional expectation.
    - Multivariates: marginals, Gaussian (properties), characteristic function, change of variables (Jacobian.)

- **Random processes**
    - Definition of a random process, finite order densities.
    - Markov chains.
    - Auto-correlation functions.
    - Stationarity–strict sense, wide sense. Examples: iid process, random-phase sinusoid.
    - Ergodicity, Central limit theorem.
    - Spectral density.
    - Response of linear systems to stochastic inputs – time and frequency domain.
    - Time series models: AR, MA, ARMA

Lectures 9-16: Detection, Estimation and Inference

- Basic linear estimation theory: BLUE, MMSE, bias, variance
- Wiener filters
- Matched filters
- Least squares, maximum likelihood, Bayesian inference.
- The ML/Bayesian linear Gaussian model
- Maximum likelihood and Bayesian estimation
- Example inference models: frequency estimation, AR model, Estimation of parameters for discrete Markov chain.

Coursework

Random variables and random number generation

Learning objectives:

- Understand random variables and functions of random variables and their simulation
- To study the Jacobian as used with random variables
- To experiment with methods for non-uniform random number generation

Practical information:

- Sessions will take place in [Location], during week(s) [xxx].
- This activity involves preliminary work.

Full Technical Report:

Students will have the option to submit a Full Technical Report.

Booklists

Please refer to the Booklist for Part IIA Courses for references to this module, this can be found on the associated Moodle course.

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.

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.

D4

Ability to generate an innovative design for products, systems, components or processes to fulfil new needs.

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.

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.

US3

An understanding of concepts from a range of areas including some outside engineering, and the ability to apply them effectively in engineering projects.

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Links
[1] mailto:sjg30@cam.ac.uk
[2] mailto:gtc31@cam.ac.uk
[3] https://teaching.eng.cam.ac.uk/content/form-conduct-examinations

[4] https://teaching.eng.cam.ac.uk/content/uk-spec