Module Template 2022-23

Module Code	**EEP55C03**
Module Name	**STATISTICAL SIGNAL PROCESSING**
ECTS Weighting[1]	10 ECTS
Semester taught	Semester 1
Module Coordinator/s	Associate Professor ANTHONY QUINN
Module Learning Outcomes with reference to the Graduate Attributes and how they are developed in discipline	On successful completion of this module, students should be able to: **LO1** Elicit and estimate parametric probability models for information-bearing signals and stochastic systems **LO2** Choose a data transform / analysis that is matched to (*i.e.* consistent with) the probability model **LO3** Derive prescriptive (Bayesian) solutions for key signal processing tasks, notably prediction, classification, (auto)regression and state-space filtering, in the context of a fully audited stochastic model **LO4** Derive the state-of-the-art classical solutions (least squares, Wiener and/or maximum likelihood) to these tasks, and compare them critically to the consistent Bayesian solutions of LO3 **LO5** Derive signal and system model selection criteria within countable sets of such models **LO6** Track nonstationary signals via Bayesian stabilized forgetting, and compare with classical adaptive Wiener solutions **LO7** Discover the Kalman filter as the consistent linear, Gaussian state-space filter **LO8** Derive and implement (in Matlab) recursive, finite-dimensional signal processing algorithms based on the classical and Bayesian frameworks above, for use in on-line applications, and in nonstationary environments, and drawing occasionally on available open-source datasets

	Graduate Attributes: levels of attainment To act responsibly - Attained To think independently - Attained To develop continuously - Enhanced To communicate effectively - Enhanced
Module Content	**OBJECTIVES** The main purpose of this module is to provide students with the theory and methods necessary for the design of optimal signal processing algorithms for information-bearing sequences ('signals'). Classical optimization methods are reviewed, but a central pillar is the design of optimal statistics (i.e. data transformations) that are consistent with the observer's (generative) signal model. In this way, the module explores the role of probability modelling in the development of robust and consistent (matched) signal transformations. The intention is to provide a principled pathway linking deterministic signal processing with a range of context-specific areas that require the processing of information-bearing signals. The module is organized in a way that constantly emphasizes the connection between the formal design approaches and the key algorithms comprising the modern signal processing toolbox. The assumptions that underlie these algorithms are revealed, and their critical role in machine learning and data science is emphasized. Therefore, the module reviews a range of frequency transforms and spectrum estimation techniques, exploring the limited conditions under which they perform well, and ways in which they can be evolved to cope with more realistic conditions. Parametric (Wold-type) modeling of random processes is reviewed as a basis for signal prediction and compression. Wiener-type estimation strategies are compared to probabilistic (maximum likelihood and Bayesian) approaches. Classification and regression problems – as canonical machine learning tasks - are a major focus. A priority is to derive principled techniques for the design of recursive, finite-dimensional estimation strategies (and, therefore, implementable real-time algorithms) for on-line signal processing, and to adapt them consistently in nonstationary environments. The module's design and methodology are ones of reviewing classical methods, auditing their assumptions, and using probability modelling to adapt them for consistency if need be. This encourages the engineering student to be critical and creative in their choice of signal processing algorithm for their own application; it primes them for design innovation in application domains; and it points them to opportunities for novel contributions to signal processing at research level.

	SYLLABUS • Review of transform analysis strategies for deterministic signals • Parametric modelling of regular random processes, and their transform analysis • Classical frequency and power spectrum estimation methods • Wiener – and related – optimization strategies for estimation: contexts in prediction, filtering and smoothing • Classical approaches to adaptive signal processing in nonstationary contexts • Probabilistic design of signal processing algorithms: maximum likelihood and Bayesian strategies • Contexts in the design of matched transforms, classification and regression • Conjugate design of recursive, finite-dimensional signal processing algorithms, and adaptive variants • Inference of hidden fields: classical and Bayesian (Kalman) filtering
Teaching and Learning Methods	The module is delivered via about 44 in-person sessions in College lecture rooms. These sessions are recorded and made available as a supplementary learning resource via Blackboard Collaborate Ultra (BbCU). A 3:1 ratio is maintained between theory and tutorial content during the contact sessions. Problem-solving experience is vital, and is gained primarily via the tutorial exercises and the in-session discussions, and also via the approximately six homework sheets distributed uniformly across the semester. A priority of the module is to demonstrate how statistical signal processing theory enables the design of implementable algorithms (**LO8**). Therefore, Matlab-based computational implementations will be developed during a series of five two-to-three-hour laboratories in each of weeks 8 to 12. In-person attendance at all module contact sessions is compulsory, to the extent that is practicable, and this is vital for the acquisition of the learning outcomes.

70% of the final module mark is determined via the formal post-module examinations. They comprise a Theory paper, and a Matlab-based Practice paper. The remaining 30% is reserved for continuous assessment, by means of two in-semester continual assessments, and a one-hour end-of-semester quiz, as scheduled below.

Assessment Details

Assessment Component	Assessment Description	LO Addressed	% of total	Week due
Two in-semester assessments	Written tests (between 30-50 minutes apiece)	1-4	15	5, 10
End-of-term quiz	Written test (1 hour)	1-8	15	12
Theory examination	Written paper (2 hours)	1-8	40	Semester-1 assessment period
Practice examination	Matlab-programming-based examination (2 hours)	1-8	30	Semester-1 assessment period

Reassessment Requirements

There is no reassessment of this module.

Contact Hours and Indicative Student Workload Error! Bookmark not defined.

Contact hours: 59
Independent Study (preparation for module and review of materials): 95
Independent Study (preparation for assessments, incl. completion of assessments): 67

Recommended Reading List

The primary learning resource will be the full set of lecture notes developed in real time during the in-person contact sessions, providing a unique record of the module. Audio-visual recordings of the sessions and their notes will be available for persistent access in BbCU. Tutorial sheets, various self-study resources, etc., will also be distributed within the module in Blackboard.

	The following books may also support the student's learning in this module: • Proakis, J.G., Manolakis, D.K., *Digital Signal Processing,* 4th ed., Prentice Hall, 2007. • Moon, T.K. and Stirling, W.C., *Mathematical Methods and Algorithms for Signal Processing.* Prentice Hall, 2000. • Haykin, S., *Adaptive Filter Theory.* Prentice Hall, 2002. • McClellan, J.H., Burrus, C.S. *et al., Computer-Based Exercises for Signal Processing.* Prentice Hall, 1998.
Module Pre-requisite	Digital Signal Processing (e.g. 4C5); Probability and Statistics (e.g. 3E3); Signals and Systems (e.g. 3C1); Engineering Mathematics (up to Year 3 incl.)
Module Co-requisite	None
Module Website	See module in Blackboard
Are other Schools/Departments involved in the delivery of this module? If yes, please provide details.	No
Module Approval Date	
Approved by	
Academic Start Year	
Academic Year of Date	