

ES4G4-15 Nonlinear Control and Reinforcement Learning

24/25

Department

School of Engineering

Level

Undergraduate Level 4

Module leader

Sina Saffaran

Credit value

15

Module duration

10 weeks

Assessment

100% coursework

Study location

University of Warwick main campus, Coventry

Description

Introductory description

The primary aim of this module is to expand upon students' existing understanding of control systems, introducing them to sophisticated methodologies and approaches in nonlinear control and reinforcement learning. The module is designed to equip students with the theoretical foundations and practical skills necessary to analyse, design, and implement control systems that address the complexities and dynamic nature of real-world nonlinear engineering problems. The course aims to foster a comprehensive understanding of how these advanced methods can enhance performance in various sectors, including engineering disciplines such as aerospace, automotive, robotics, and energy systems, as well as AI and data-driven technologies. Through this module, students will be prepared to innovate and apply cutting-edge control solutions to a multitude of engineering challenges, reflecting the evolving demands of contemporary and future technologies.

Module aims

Becoming proficient in two cutting edge approaches to nonlinear control: model predictive control theory and reinforcement learning, emphasising their relevance and application in current industry practice rather than focusing on outdated or theoretical-only approaches.

Utilising state-of-the-art software tools (e.g. the Matlab Model Predictive Control Toolbox and Reinforcement Learning Toolbox) to model, analyse, and implement control and optimisation strategies, enabling students to tackle complex, real-world problems with sophisticated computational resources.

Integrating real-world constraints and challenges, such as nonlinearity, system uncertainties, and environmental interactions, into our problem-solving approach to ensure that the solutions students develop are applicable in practical scenarios.

Applying the theoretical concepts to a wide range of applications, illustrating the versatility and impact of nonlinear control and reinforcement learning through concrete examples and case studies, complemented by relevant software demonstrations and simulations.

Outline syllabus

This is an indicative module outline only to give an indication of the sort of topics that may be covered. Actual sessions held may differ.

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- Introduction to Model Predictive Control (MPC) Systems, its core principles and formulation
- Objective functions in MPC and designing cost functions for optimal control performance
- MPC without constraints, its theory and applications
- Control horizon and prediction horizon, their roles in MPC performance and computational complexity
- MPC with constraints, incorporating various constraints in MPC
- Overview of optimisation techniques used in MPC (linear programming, quadratic programming)
- Sequential Quadratic Programming (SQP) for solving nonlinear MPC problems
- Implementation challenges and solutions in MPC, scalability and computational aspects
- Review of key probability concepts, and introduction to Reinforcement Learning (RL)
- Exploration vs. exploitation dilemma, value iteration and policy iteration
- Introduction to core algorithms in RL such as Q-learning, State–action–reward–state–action (SARSA)
- Comparing model-free and model-based approaches
- Designing effective reward functions
- Application of RL algorithms to control tasks, differences and synergies between RL and traditional control methods
- Ensuring stability and robustness in RL control systems
- Combining nonlinear control techniques with reinforcement learning for advanced control solutions

Learning outcomes

By the end of the module, students should be able to:

- Understand, identify and describe the key characteristics and challenges of nonlinear systems and their implications for control system design and analysis [M1, M2, M6].

- Apply basic nonlinear control techniques to stabilise and control nonlinear systems, understanding the underlying principles and limitations of these strategies [M1, M2].
- Design and analyse Model Predictive Control (MPC) Systems, both with and without constraints, understanding the formulation, optimisation, and implementation aspects of MPC [M1, M2].
- Understand and explain the core principles of Reinforcement Learning (RL), including the concepts of agents, environments, states, actions, rewards, policies, and value functions [M1, M2].
- Design and implement fundamental Reinforcement Learning algorithms such as Q-learning and policy gradient methods, to solve decision-making problems [M1, M2].
- Evaluate the performance of various reinforcement learning algorithms, understanding how factors like exploration vs. exploitation and discounting affect outcomes [M1, M2].
- Apply advanced software tools such as the Matlab Model Predictive Control Toolbox and Reinforcement Learning Toolbox to solve real-world problems [M3, M12].

Indicative reading list

- Maciejowski, J.M., "Predictive Control with Constraints," Prentice Hall, 2002.
- Wang, L., "Model Predictive Control System Design and Implementation Using MATLAB," Springer, 2009.
- Rawlings, J.B., and Mayne, D.Q., "Model Predictive Control: Theory and Design," Nob Hill Publishing, 2009.
- Sutton, R.S., and Barto, A.G., "Reinforcement Learning: An Introduction," 2nd edition, MIT Press, 2018.
- Szepesvári, C., "Algorithms for Reinforcement Learning," Morgan and Claypool Publishers, 2010.
- Matlab Model Predictive Control Toolbox, User's Guide, Mathworks
<https://uk.mathworks.com/help/mpc/>
- Matlab Reinforcement Learning Toolbox, User's Guide, Mathworks
<https://uk.mathworks.com/help/reinforcement-learning/>
- Franklin, Powell, and Emami-Naeini, Feedback Control of Dynamic Systems (7th Edition), Pearson, 2014.
- Hahn and Valentine, Essential MATLAB for Engineers and Scientists, Academic Press, 2019.

Interdisciplinary

Between Control Engineering and Computer Science (Reinforcement learning)

Subject specific skills

Nonlinear system analysis

Model predictive control design and analysis

Formulation of optimisation problems and integration of constraints in MPC

Simulation and computational tools for model predictive control

Designing, implementing and tuning various Reinforcement Learning algorithms

Policy optimisation in Reinforcement Learning
Simulation and computational tools for reinforcement learning systems.

Transferable skills

Intelligent Control, Adaptive Control, Machine Learning, MATLAB Programming, Technical Report Preparation, Problem Solving, Critical Thinking

Study

Study time

Type	Required
Lectures	12 sessions of 1 hour (8%)
Practical classes	4 sessions of 4 hours (11%)
Private study	122 hours (81%)
Total	150 hours

Private study description

The following is a suggestion of how the hours of private study could be used:

- Directed reading on key concepts prior to classes
- Preparation for labs (e.g. revision from ES3C8 or similar)
- Research for individual assignments
- Preparation of individual assignment reports

Costs

No further costs have been identified for this module.

Assessment

You must pass all assessment components to pass the module.

Assessment group A

	Weighting	Study time
Model Predictive Control Assignment	50%	
Students will be provided with a challenging real-world case study, including the system model, design specifications to be achieved, and suggested design and analysis methods to be used.		

Weighting

Study time

Students will design and analyse a model predictive controller using Matlab and verify satisfaction of design and performance specifications.

The students will present their results in a written format through a report.

Reinforcement Learning (RL)
Assignment 50%

Students will be provided with a challenging real-world case study, including the system model, design specifications to be achieved, and suggested design and analysis methods to be used. Students will design and analyse a reinforcement learning algorithm using Matlab (or Python) and verify satisfaction of design and performance specifications.

The students will present their results in a written format through a report.

Feedback on assessment

Cohort feedback.

Individual written feedback.

Availability

Pre-requisites

To take this module, you must have passed:

- All of
 - [ES3C8-15 Systems Modelling and Control](#)

Courses

This module is Optional for:

- Year 5 of UESA-H115 MEng Engineering with Intercalated Year

This module is Option list A for:

- Year 4 of UESA-H114 MEng Engineering
- Year 4 of UESA-HH31 MEng Systems Engineering
- Year 5 of UESA-HH32 MEng Systems Engineering with Intercalated Year