Fundamentals of AI and Machine Learning for Control Engineers: Course Agenda

Introduction to AI for Practical Control and Condition Monitoring

Artificial Intelligence (AI) and Machine Learning (ML) has received a new impetus in recent years and offers opportunities for services and products. There are many areas where artificial intelligence and machine learning is already having an impact that will affect industrial control systems design, ranging from the design procedures to the improvement in the performance and robustness of systems. AI and ML offer solutions to some of the most difficult problems. For example, how to reduce the design time and commissioning time for systems that have difficult dynamics.

Artificial intelligence can be utilised in control applications in two main ways. The first involves data analysis where big data can be used to inform management actions or initiatives. The second is focused on the use of AI to provide improvements in control or signal processing systems at an electro-mechanical machine or local plant level, including the use of digital twins for modelling, prediction and condition monitoring. The use of AI methods for data analysis is where much of the previous attention was focused but from a control engineers' perspective it is the data driven machine leaning control methods that are of most interest. These provide opportunities to introduce new types of adaptive controllers, filters and condition monitoring tools that can introduce compensation for uncertainties in system or signal characteristics.

There are many developments in this area and one of the main aims of the course is to pick out the advances that are of most importance to control engineers. The course will introduce some of the most significant results and priority areas. For example, the influence of AI methods on system modelling and control design provides a different philosophical approach and therefore new opportunities to improve performance and reduce engineering design effort.

Both pure data driven black box AI based methods and those that combine AI and model-based methods will be described, and the relative advantages discussed. The latter are attractive since pure data driven modelling methods can be useful, but it is a pity to ignore good physical system model information. A benefit of combining AI and traditional model knowledge and control methods is that plant engineers may have great confidence in an existing controller, even if the performance is limited. They are therefore likely to be more receptive to enhancing such solutions rather than using a radically new approach. Improving solutions via the data available is a cautious step but it can provide significant performance improvements. Moreover, if under some conditions the data does not improve a solution, the system can revert to the original controller seamlessly.

The ways in which AI and ML will satisfy the practical demands of an engineering system will be covered including the requirements and physical constraints that must often be met. The main aim of a control system is often to provide reliable and consistent performance, in the presence of uncertainties. The effective use of data can at least partly address the uncertainty problem. The second most important aim of many systems is to optimise performance, and in this case the relatively new meta-heuristic AI inspired

optimisation algorithms can be valuable. Data driven methods can also be used to mitigate the deleterious effects of nonlinearities.

The course is introductory and aims to provide an intuitive understanding supported by hands-on simulation examples using MATLAB/Simulink. The PowerPoint presentations will include notes that can be used as an aide-memoire. There will also be software demonstrations and opportunities to discuss the material, or ask questions, at the end of the presentations and at the end of each session.

Day 1: Artificial Intelligence Fundamentals

09.00 Welcome, Safety and Introduction to the Course

09.10 L1.1: Introduction to Intelligent Control and Machine Learning I

Core ideas in artificial intelligence, motivation, terminology, brief history of AI systems, classification problems, big data, deep learning, importance of AI in control applications.

10.15 TEA/COFFEE

10.30 L1.2: Introduction to Intelligent Control and Machine Learning II

Historical perspective, main ideas and techniques, machine learning, reinforcement learning, developments in AI, multi-agent systems, possible application areas, benefits in applications.

11.30 L1.3: Different Approaches to Modelling Systems

Including the AI approach to modelling and the physical system model equation-based methods (model based), and system descriptions, parameterisation of models.

12.30 LUNCH

13.30 L1.3: Meta Heuristic Optimisation and Gradient Algorithms

AI based optimisation algorithms for linear and nonlinear systems, for training parameters, gradient methods.

14.30 TEA/COFFEE

14.45 L1.3: Neural Networks

Introduction to neural networks, neurons, activation functions, types of NN, forward and backward propagation, layers of neural networks, network structures, loss functions, advantages and disadvantages, and use in condition monitoring, fault detection and prognostics.

16.00 D1.1: Neural Networks Design Demonstration

Design and comparison of different NNs for torque demand prediction

17.00 CLOSE

Day 2: Artificial Intelligence in Modelling and Classical Control

09.00 L2.1: Digital Twins for Control and Monitoring Applications
Digital Twin for modelling, condition monitoring, prediction, and control

10.00 TEA/COFFEE

10.15 L2.2: Support Vector Machine Approach to System Identification
AI and SVM methods on modelling and system identification

11.30 D2.1: Demonstration Support Vector Machine Approach to System Identification
SVM data-driven design tool demo/hand-on

12.30 LUNCH

13.30 L2.3: Classical Control and use with AI/ML Methods
AI/ML methods for improving classical controllers, Neural Network Based Reinforcement, Learning for Automotive Control.

14.30 TEA/COFFEE

14.45 L2.4: AI in Control Systems: Limits and Advantages
Review of the role of AI in control system with discussion of limits, issues, and reasons for using together with advanced control.

15.45 L2.5: Relationship between Fuzzy Logic Based Algorithms and AI Method
Introduction to Fuzzy Control and links to AI, Neuro-fuzzy application.

17.00 CLOSE

Day 3: Artificial Intelligence in Advanced Controls

09.00 L3.1: Optimisation and Optimal Control in AI Enhanced Systems
Introducing AI methods into Nonlinear and Predictive Controls, Use of Genetic Algorithms, Why AI is important in applications, such as automotive and examples.

10.00 TEA/COFFEE

10.15 L3.2: Introduction to Model Predictive Control
Motivational introduction to MPC methods and the solution approach, and why it is so successful, where it has advantages, and briefly overviews competing methods that are options such as classical, LQG, H∞ robust and nonlinear control design methods.

11.30 L3.3: AI Enhanced Model Predictive Control
The AI role in controllers design, AI for modelling/control/calibration, Introduction to the example AI predictor for LPV-MPC in automotive application.

12.30 LUNCH

13.30 D3.1: Hybrid-Electric Vehicle MPC-LPV Energy Management System Demonstration
Model Predictive Control-based Energy Management System and Benchmarking, the role of prediction and different predictor structures.

14.30 TEA/COFFEE

14.45 L3.4: Review of the Current State of Combined AI and Control System Techniques
Review of the literature on combined AI and control techniques, new ideas and potential for modern control techniques and new developments.

16.00 Discussion: Commercial Developments and Machine Learning Tools - Debate

16.30 CLOSE

Course Content Notes

The AI methods include areas such as neural networks, learning systems, digital twins, fuzzy logic, and control, and they utilise optimisation techniques such as genetic algorithms. These topics will be considered and an engineering perspective on AI and machine learning will be provided. The way control algorithms can be improved using AI methods will be described, such as introducing model knowledge into classical, modern-nonlinear, and predictive control algorithms.

Introduction and Benefits of AI based modelling techniques

- Neural Networks and Deep Learning
- Support Vector Machines

Introduction to Artificial Intelligence, Machine Learning, and Deep Learning

Categories of machine learning algorithms

- Supervised learning
- Unsupervised learning
- Reinforcement learning

Applications of machine learning algorithms

Learning systems and modelling: for design optimisation

- machine learning models
- types of data and analysis
- choosing the model structure
- choice of loss function and optimisation algorithm
- assessing performance
- tools and software

Control Application Studies

- Different application areas.
- Form of data and physical model availability
- Modelling approaches
- Data editing/cleaning/sampling
- Simulating systems

Assessing Model Performance

- Performance assessment of ML models
- When to use machine learning models and problems
- Bias in models
- AI based and combined physical Models.