MECH4000P – AI in Mechanical Engineering (Spring 2023-24, 3 credits)

Instructor

Prof. Wenqi HU

Course Description

This course delves into the integration of Artificial Intelligence (AI) principles and technologies within Mechanical Engineering, beginning with an introduction to AI to establish a foundational understanding of its role in contemporary engineering solutions. With the help of the instructor, students will first explore three pivotal areas:

- **Dimensionality Reduction and Transforms**: Techniques like Singular Value Decomposition and Fourier Transforms are taught to enable the simplification of complex data, facilitating more straightforward analysis and engineering application.
- **Machine Learning and Data Analysis**: Students will gain critical machine learning skills, including regression and clustering, tailored for mechanical engineering challenges such as predictive maintenance and system design optimization.
- **Dynamics and Control**: The course underscores the application of data-driven methods in dynamics and control, equipping students to improve mechanical system performance and efficiency through AI strategies.

Practical Application

Practical application is central to the course, with potential projects ranging from developing **(1) AI-based controls for robotic arms** to **(2) crafting cilia-inspired fluid flow controllers for water tanks**, and **(3) using AI to optimize pipe network flow in simulation***. These projects serve a dual purpose: they provide hands-on experience and also reinforce theoretical principles, illustrating the investigative process in action. Students will collaborate in teams to tackle these real-world engineering challenges, applying AI strategies in a practical, exploratory context.

* Reflecting on the feedback on class instructions, the content of these three projects is subject to modification.

Learning Objectives

By the end of this course, the students will be able to:

1. **Fundamental AI Concepts**: Understand the core principles of artificial intelligence and machine learning, and their applications in mechanical engineering.
2. **Data Analysis Proficiency**: Analyze and interpret complex data sets using AI techniques such as dimensionality reduction and machine learning algorithms.
3. **Control Systems Integration**: Integrate AI with control principles to enhance the performance and efficiency of mechanical systems.
4. **Scientific Communication**: Communicate proficiently, enabling clear and effective documentation of technical content and research findings.
5. **Collaborative Engineering**: Work effectively in a team, developing collaborative problem-solving and project management skills within multidisciplinary engineering projects.

Prerequisite (One of the following courses is required):

- COMP1021 or COMP1022P or COMP2011 or COMP2012H

Target Student Group

- MAE UG students (Year 3 & 4). Priority will be given to MECH and AE students with extended major in AI.

Class Quota: 45

Textbook

- **"Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control" by Steven L. Brunton and J. Nathan Kutz**.

Reference Books

- **"Artificial Intelligence: A Guide for Thinking Humans" by Melanie Mitchell** - Offers a clear and accessible overview of AI, including its application in robotics.
- **"Introduction to AI Robotics" by Robin R. Murphy** - This book provides a comprehensive introduction to the use of AI in robotics, covering both theoretical and practical aspects.
- **"Robotics, Vision and Control: Fundamental Algorithms in MATLAB" by Peter Corke** - Ideal for hands-on learning, this book focuses on vision and control aspects in robotics, with practical examples in MATLAB.
- **"Python Machine Learning" by Sebastian Raschka and Vahid Mirjalili** - A great resource for learning machine learning concepts using Python, covering various algorithms and practical applications.
- **"Computational Fluid Dynamics: A Practical Approach" by Jiyuan Tu, Guan Heng Yeoh, and Chaoqun Liu** - This book is widely regarded for its practical approach to CFD. It provides foundational knowledge in fluid dynamics and numerical methods, which are essential when integrating AI techniques into fluid dynamics simulation.

Grading Policy (Letter grade A – F)

Homework	Midterm Exam	Final Project and Report	Quiz
15%	15%	65% (project involvement 45%, final report 20%)	5%

*The purpose of the final projects is to encourage students to apply theoretical knowledge and AI techniques to conduct thorough investigations in their projects, with an emphasis on the research process and learning from practical experience, not on the outcome of the projects.

*Final projects will be repeated used as examples during first eight weeks' class instructions.

*Final projects will be supported by the instructor's lab.

Course Schedule

Weeks 1-2: Introduction to AI in Mechanical Engineering (Class instruction)

- Fundamental concepts
- Impacts and examples on mechanical engineering.

Weeks 3-4: Dimensionality Reduction and Transforms (Class instruction)

- Singular value decomposition (SVD).
- Fourier and wavelet transforms.
- Sparsity and compressed sensing.

Weeks 5-6: Machine Learning and Data Analysis (Part 1) / Introduction to Three Class Projects

- Regression and model selection.
- Clustering and classification.
- Midterm will be carried out during this week to ensure students have a basic grasp of the fundamental knowledge before proceeding to work on final projects.
- Class introduction of three well-selected class projects. It is for giving students an overview of these projects.

Weeks 7-8: Machine Learning and Data Analysis (Part 2) / Initial Project Development

- Neural Network and Deep Learning. (Class instruction)
- Students select one of three projects to form teams. (Lab)
- Teams start to work on projects. (Lab)

Weeks 9-10: Dynamics and Control (Part 1)

- Data-driven dynamical systems. (Class instruction)
- Linear control theory. (Class instruction)
- Teams continue working on their projects and receiving feedback. (Lab)

Weeks 11-12: Dynamics and Control (Part 2)

- Balanced models for control. (Class instruction)
- Data-driven control. (Class instruction)
- Instructors and TAs give additional guidance for project refinement. (Lab)

Week 13: Final Project Presentations and Course Review

- Final presentations by each team. (Lab)
- Writing final report by each student. (Lab)
- Wrap-up review of course content in the context of project experiences. (Class instruction)