AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
MECHATRONICS ENGINEERING DEPARTMENT
Credit Hours Programs

Fall, 2025

MCT 343: Mechatronics Applications

Project Objectives:

The MCT 343 Course provides 3 projects from which the students can select from. Each team **(5 – 6 members per team)** can select one of the following projects to be implemented based on there interest in recent mechatronics applications. The first project is based on **Nanomechatronics** and its simulations using Ansys in which a MEMS device operation is simulated. The second project is based on **Biomechatronics** applications with data collection and processing with biomechanical motion analysis. The third project is based on **Autotronics** applications in which MATLAB is used to simulate vehicle dynamics in scenarios testing the lateral, longitudinal, and vertical dynamics modelling.

Project 1: Modelling of Comb Drive as MEMS Actuator

- **Project Description**

The students will develop a finite element model of a comb drive as a MEMS electrostatic actuator. The students will work in teams on this task to achieve the requirements. The task is intended to provide students with skills needed to define boundary conditions for a correct MEMS device simulation, while knowing more about material selection and properties and how they affect the MEMS device performance.

- **Learning Outcome to be assessed**

1. Apply mechanisms of operation of modern MEMS sensors, actuators and measuring instruments in different fields of application.
2. Interpret the basic analysis and design tools (Finite Element Modeling) of MEMS based actuators and sensors.
3. Share ideas with others effectively.
4. Gain access to data and information from libraries and internet related to course subjects.

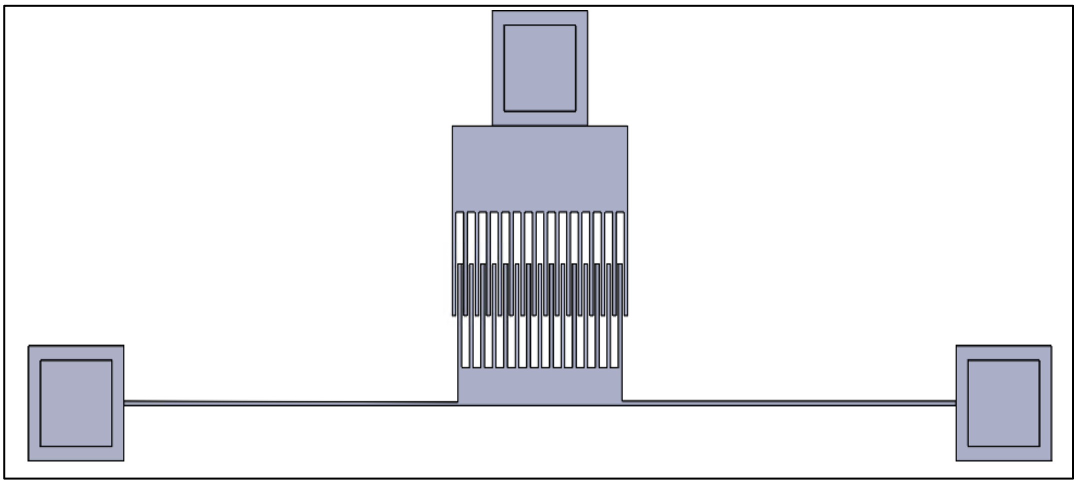
- **Detail of the task**

This task requires the students to develop a finite element model of a comb drive as a MEMS electrostatic actuator. The modeling will be conducted on ANSYS Software.
Students are required to:

- create the CAD of the comb drive actuator and import it to ANSYS.
- Define suitable material properties.

- Set proper boundary conditions for the FE model to actuate the comb drive using electrostatic physics.
- Extract the FE results: total and directional deformation, Von Misses stress and strain, normal stress and strain, and voltage distribution.

The aim of the individual work is to ensure that each student learns how to integrate the previously developed FE models covered in the labs for finite element modeling of MEMS/NEMS devices. The students are required to produce a report/or presentation to



illustrate their work.

- **What you should hand in**

Video: Showing simulation for the FE model during the actuation of the comb drive. The video should also include detailed walkthrough showing the steps followed to simulate the MEMS device and proper explanation.

Report: One member per team should submit there work as software files and a soft copy of a digital report. In addition, students should submit the report as a hardcopy and/or softcopy on A4 papers. Make sure the report has a cover page showing the team members and there contributions to the project submitted.

Project 2: Biomechanical Motion Analysis of Hand Model and EMG

- **Project Description:**

  This project focuses on developing a 3D virtual model of a prosthetic hand with five independently controlled fingers, driven by electromyography (EMG) muscle signals. Students will use one or more software tools—such as SolidWorks, MATLAB, Unity, Python, ROS, Gazebo, Issac sim, opensim, or Unreal Engine—to design and simulate the hand. The goal is to create a control system where processed EMG signals enable realistic opening and closing movements of the prosthetic fingers 3D model, mimicking the operation of a real physical prosthesis.

The project involves a complete pipeline, starting with EMG data collection. One team member will be responsible for acquiring the raw EMG telemetry in human centered mechatronics lab (HCM), which will be provided as a JSON file. Each team will preprocess this data, converting it to a CSV format and applying signal processing techniques to filter noise, extract features, and identify dominant muscle activation channels for gesture detection.

Using the processed EMG signals, students will design a virtual prosthetic hand model in CAD software and import it into a simulation environment of their choice, such as MATLAB Simscape, OpenSim, Isaac Sim, Gazebo/ROS, unity, unreal, or other suitable platforms. Two or more dominant EMG channels from the provided dataset will be selected to control at least two gestures, such as full hand/fingers opening and closing, with the option to extend to proportional finger control.

Students will have flexibility in designing the control logic, choosing between threshold-based logic with if-then rules, stateflow-based control in MATLAB, or machine learning and AI approaches for gesture classification and movement prediction. The project also encourages implementing Hardware-in-the-Loop (HIL) or Processor-in-the-Loop (PIL) simulations, enabling real-time testing and validation of the control strategies on a virtual prosthetic hand prototype.

Through this project, students will gain hands-on experience in EMG signal processing, biomechanical modeling, control system design, and simulation-based prototyping for next- generation assistive technologies.

- **Project Workflow:**
  - **Data Parsing and Preparation:**
    Raw EMG telemetry provided in JSON format must be parsed and converted into a clean, well-structured CSV file suitable for further analysis and processing.
  - **Signal Preprocessing:**
    The EMG signals should undergo standard preprocessing procedures, including rectification, filtering, and noise reduction, to ensure the data quality is appropriate for subsequent feature extraction and analysis.
  - **Comprehensive Signal Analysis:**
    Both fundamental and advanced signal-processing techniques must be applied to the EMG dataset. This should include analyses across the time domain, frequency domain, and time– frequency domain to explore the characteristics of the signals and enhance understanding for control logic development.
  - **Channel Selection:**
    Using appropriate signal-processing metrics, two or more dominant EMG

channels must be identified from the provided 14-channel dataset to serve as control inputs for the prosthetic hand simulation.

- **Prosthetic Hand Modeling:**
  A detailed CAD model of the prosthetic hand or human hand must be designed and exported, then imported into a suitable simulation environment (e.g., MATLAB Simscape, Unity, Unreal Engine, OpenSim, or ROS-based simulators) for visualization and control testing.
- **Gesture Detection and Mapping:**
  At least two distinct hand gestures (e.g., open hand, closed fist, or other finger movements) must be detected using threshold-based logic, with the option to implement machine learning techniques if desired. The detected gestures should then be accurately mapped to control the movements of the virtual prosthetic hand model in real time.

- **Progress Checkpoints:**

  1) **Milestone 1 (by Week 11):** Data collection completed and Application of signal preprocessing and processing techniques, Prosthetic hand / hand model CAD design.
  2) **Milestone 2 (Final Week):** The final submission should include a fully functional virtual 3D prosthetic hand model controlled using simulated EMG data, designed to replicate real EMG muscle signals for realistic control and operation. Or a biomechanical hand model with motion analyzed and compared to collected data.

- **Deliverables:**
  - ➢ Original supplied JSON & Parsed CSV File
  - ➢ CAD, Simulation and Code file
  - ➢ Working Simulation on the submission day.
  - ➢ Video with voice narrations (5 minutes max) showing a fully functional simulation
  - ➢ A Technical report with a contribution table

<u>Project 3: Vehicle Dynamics Integrated Simulation using MATLAB</u>

- **Project Description:**

This project provides students with hands-on experience modeling, simulating, and controlling vehicles using MATLAB. Students will integrate three vehicle dynamics domains — lateral (cornering and yaw), longitudinal (acceleration and braking), and vertical (ride comfort and suspension). They will also design and tune a PID controller to improve performance metrics like speed stability, ride comfort, or yaw control. Teams will build a MATLAB simulation that integrates all three dynamics domains. The simulation should depict a realistic driving event involving acceleration/braking, cornering, and vertical motion. Students will design and implement a PID controller to stabilize or optimize chosen variables and compare open-loop and closed-loop performance.

- **Required Libraries**

Teams must install and use all three open-source MATLAB libraries:

1. Vehicle Dynamics - Lateral: simulates steering, yaw motion, and cornering.
2. Vehicle Dynamics - Longitudinal: models vehicle acceleration, braking, and traction.
3. Vehicle Dynamics - Vertical: represents suspension dynamics and tire-road contact.

- **Project Tasks & Workflow**
  - Prepare MATLAB Libraries and explore each library individually. Run examples, identify key states, inputs, and outputs.
  - Define an integrated simulation scenario combining the three modules. Ensure signal coupling between domains (e.g., tire load, suspension deflection).
  - Design a PID controller using MATLAB tools. Tune parameters to meet performance goals and verify improvement. Variables to be controlled using PID control include longitudinal speed and lateral yaw angle (orientation of the car). These need to follow specified set points needed to achieve the scenario you are simulating.
  - Conduct parameter sensitivity study. Analyze how changing mass, stiffness, or damping affects results. Apply this to lateral parameters as well.
  - Finalize report and video demonstrating your model and control strategy.

- **Deliverables**

Each team must deliver:

- MATLAB scripts implementing the full model with PID control.
- A detailed report covering theory, methods, results, and analysis.
- Video summarizing findings with visuals and plots and explaining the followed steps to simulate the scenario.

Every team must demonstrate that:

1. All three dynamic modules are properly linked and running in MATLAB.
2. A functional PID controller is implemented and tuned.
3. The controller improves system behavior compared to the open-loop case.
4. The report includes interpretation of results and reflections on trade-offs.

- **Evaluation Criteria**

Assessment will consider:

- Integration of all three modules.
- Quality of PID controller design and justification.
- Correctness of physical modeling and signal coupling.
- Clarity and structure of the report and visuals.
- Innovation and demonstration quality.

- **Possible Extensions (Bonus)**

- Benchmark controller performance against alternative advanced control strategies (e.g., LQR, fuzzy logic).
- Simulate sensor noise and apply Kalman or low-pass filters.

- **Expected Learning Outcomes**
  Upon completion, students will: - Understand the physics behind lateral, longitudinal, and vertical vehicle dynamics. - Integrate these models in MATLAB. - Design and tune PID controllers for multi-domain systems. - Evaluate dynamic performance and control improvements. - Produce professional technical documentation.

- **Example Scenario**
  Example event: A vehicle accelerates from 0–100 km/h, enters a 100 m radius curve, and crosses a 0.05 m bump while maintaining speed and stability. The task is to integrate vertical, longitudinal, and lateral dynamics, and implement a PID controller to improve ride comfort or yaw stability.

Marking Criteria for all Projects

89% and above:

Your work must be of outstanding performance and fully meet the requirements of the coursework specification and learning outcomes stated. You must show independent thinking and apply this to your work. There must be evidence of originality and wider reading on the software features. In addition, your proposed solution should:

- A perfectly running simulation with no errors,
- Express a deep understanding of each step to prepare the simulation,
- Applying the learned knowledge to prepare a perfectly running simulation with no errors.

76% - 89%:

Your work must be of good quality and meet the requirements of the coursework specification and learning outcomes stated. You must demonstrate some originality in your work. There must be evidence of wider reading on the software features. In addition, your proposed solution should:

- A good running simulation,
- Express a very good understanding of each step to prepare the simulation,
- Applying most of the learned knowledge to prepare a good running simulation.

67% - 76%:

Your work must be comprehensive and meet all of the requirements stated by the coursework specification and learning outcomes. You must show a good understanding of the key features of the software and be able to apply them to your work. There must be enough depth to your work to provide evidence of wider reading on the software features. In addition, your proposed solution should:

- A moderate ability of preparing the simulation,
- Express a good understanding of the steps to prepare the simulation,
- Applying most of the learned knowledge, correctly, in the prepared solution.

60% - 67%:

Your work must be of a standard that meets the requirements stated by the coursework specification and learning outcomes. You must show a reasonable level of understanding of the key features of the software and apply this knowledge to the coursework problem. There should be some evidence of wider reading. In addition, your proposed solution should:

- A fair ability of preparing the simulation,
- Express a fair understanding of the steps to prepare the simulation,
- Applying some of the learned knowledge, correctly, in the proposed solution.

Below 60%:

Your work is of poor quality and does not meet the requirements stated by the coursework specification and learning outcomes. There is a lack of understanding of the key features of the software and no evidence of wider reading. In addition, your proposed solution would be:

- An inability of preparing the simulation,
- Failed to define the correct parameters of preparing the simulation,
- Failed to apply correctly the learned knowledge for proposing a valid simulation.

Academic Misconduct

The University defines Academic Misconduct as ‘any case of deliberate, premeditated cheating, collusion, plagiarism or falsification of information, in an attempt to deceive and gain an unfair advantage in assessment’. This includes attempting to gain marks as part of a team without making a contribution. The department takes Academic Misconduct very seriously and any suspected cases will be investigated through the University’s standard policy. If you are found guilty, you may be expelled from the University with no award.

It is your responsibility to ensure that you understand what constitutes Academic Misconduct and to ensure that you do not break the rules. If you are unclear about what is required, please ask.

Project Final Submission evaluation criteria

Course Code:	……………	**Course Name:**	…………………………	**Project Final Submission**	…….	**Date :**	…………… ……………
Student Name:	…………………………………………………………………………			Student ID:	…………………………		

	A (89-100)	B (76-88)	C (67-75)	D (60-66)	F (0-59)
	100 96 92 89	88 84 80 76	75 72 69 67	66 64 62 60	59 40 20 0
Report (50%)	• Clear and relevant research methodology with complete implementation • Excellent analysis of results and complete relevant conclusions	• Clear and relevant research methodology missing few components • Good analysis of results missing some minor conclusions	• Clear research methodology missing several components some structure. • Normal analysis of results missing some basic conclusions	• Inappropriate research methodology Structure not clear. • Incomplete analysis or results with some conclusion s	• Lack of clear research methodology • Missing proper analysis or results and no conclusions at all.
Simulation Quality (50%)	• A perfectly running simulation with no errors, • Express a deep understanding of each step to prepare the simulation, • Applying the learned knowledge to prepare a perfectly running simulation with no errors.	• A good running simulation, • Express a very good understanding of each step to prepare the simulation, • Applying most of the learned knowledge to prepare a good running simulation.	• A moderate ability of preparing the simulation, • Express a good understanding of the steps to prepare the simulation, • Applying most of the learned knowledge, correctly, in the prepared solution.	• A fair ability of preparing the simulation, • Express a fair understanding of the steps to prepare the simulation, • Applying some of the learned knowledge, correctly, in the proposed solution.	• An inability of preparing the simulation, • Failed to define the correct parameters of preparing the simulation, • Failed to correctly apply the learned knowledge for proposing a valid simulation.

1st marker Total	---------	1st marker Signature	--------------------	**ASU** Agreed Mark	-----------
2nd Marker Total	---------	2nd marker Signature	--------------------	**UEL** Agreed Mark	-----------

Comments and Feedback:

UEL Grading System	Agreed Mark Range	ASU Grading Scale	
% equivalent at UEL		% at ASU	Grade
95% and higher		97% and higher	A+
82% to less than 95%		93% to less than 97%	A
70% to less than 82%		89% to less than 93%	A-
66% to less than 70%		84% to less than 89%	B+
63% to less than 66%		80% to less than 84%	B
60% to less than 63%		76% to less than 80%	B-
56% to less than 60%		73% to less than 76%	C+
53% to less than 56%		70% to less than 73%	C
50% to less than 53%		67% to less than 70%	C-
45% to less than 50%		64% to less than 67%	D+
40% to less than 45%		60% to less than 64%	D
Less than 40%		Less than 60%	F

Best Wishes
Dr./ Diaa Emad Abdel Fattah