Aalto University
School of Engineering

MEC-E5001 Mechatronic Machine Design, Project work

A project reports are to be written and returned by the deadlines to the MyCourses portal. (Note that the presentations are held before the final submission deadline, you can still improve you project work if you like). Each group creates their own report. Discussing the tasks with other groups is allowed, and even encouraged, but copying others' solutions is strictly prohibited.

Create the report in pdf format. Handwritten solutions will not be accepted. Remember to attach the requested images to your report. Show all your mathematical solutions stage by stage in the report.

In the project reports, follow the same section titles 1...3 given in the assignment paper. (1. Background study (300 p), 2. Numeric Modelling (600 p), 3. Components (600 p), 4. CAD Modeling (500 p) and 5. Simulation model and control (900 p)

Crane Hook Sway Simulation and Control: "Keikku" (500+2400+100 points)

The aim of the project work is to design a device that can demonstrate sway control feature of a crane, i.e. "keikku". You have been assigned to a group of **three (3)** people and your task is to **1) design and simulate trolley and hook system of an overhead crane and 2) apply sway control on the system.** You need to select the scale of the device yourself. Maybe the most straightforward is to do in scale similar to "Ilmatar" crane in Aalto Industrial Internet Campus.

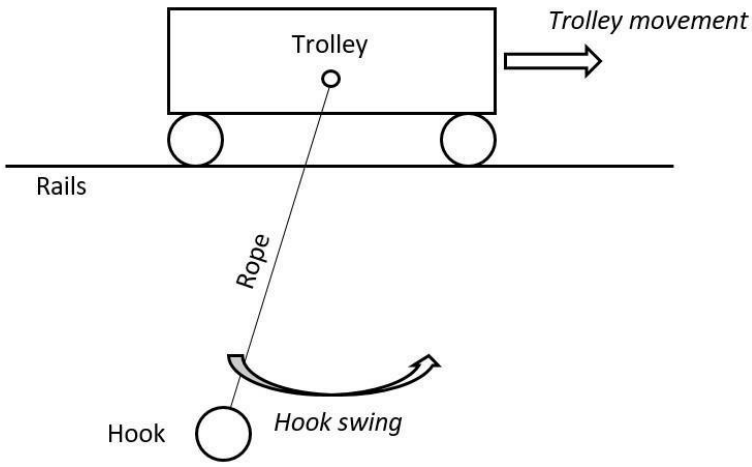

Figure 1: Trolley and hook of a crane.

The project work is laid out as a chronologic step-by-step assignment but it is recommended to be done iteratively so that when problems arise along the way you can go back and make adjustments to previous decisions.

Requirements for the project

1. **Design a "keikku" according to the tasks given**. For reference, see example values of the Ilmatar crane listed in Table 1. In the project report, follow the same section titles 1...5 given in the assignment paper. (1. Background study (300 p), 2. Numeric Modelling (600 p), 3. Components (600 p), 4. CAD Modeling (500 p) and 5. Simulation model and control (900 p)

2. **Make Project work startup submission by the first deadline.** Carry out the tasks in section 1. Background study (300 p) and give outline how you solve the other parts of the assignment (200 p). The outline includes, for example, which tools you are going to use, your schedule, who does what, etc. The total maximum is 500 p. The lecture after submission is dedicated to discussion and sharing tips regarding to group work.

3. **Make Project work final submission by the second deadline.** Carry out all the tasks. The maximum is 2400 p.

4. **Make a presentation** of your work. Every group will pitch their idea in max 5 minutes. Present only one part of your work, such as control method, with 3-5 slides.

5. Return **two** project files to A+:
    a. Project report in .pdf format.
    b. Zipped folder (.zip) for all other required files. (At least .slx and .m). Include also your presentation in .pdf or .ppt(x) format and project report in this folder.

Table 1. Reference values for the Ilmatar crane.

Rope length	L	0.5-3.0 m
Trolley max speed	v	20 m/min
Trolley movement range	L_2	9 m
Trolley weight	m_1	250 kg
Trolley motor power	P	1.5 KW
Hoist (vertical) max speed	v_2	8 m/min
Hook weight	m_2	5 kg
Lifting capacity	m_{max}	3200 kg

1. Background study (300 p)

a) Search and select **two** academic articles on the project topic. Minimum amount of text for each article is 60 words.
   i. Describe the main purpose and findings of the article. (2 x 50 p)
   ii. Describe how the article is related to the project topic. (2 x 50 p)

b) Search for existing pendulum mechanisms for reference and draw a sketch of your own system by hand or with a computer software. There are many different types of mechanisms to move the trolley. In addition, rope angle measurement needs to be considered when designing your mechanics. (The rope does not have to be a real rope, it can be a rigid stick with weight at the end.) **Attach this sketch to your report.** (100 p)

2. Numeric modelling (400 p)

a) Make force equations for horizontal and vertical forces in your system according to the Newton's Second law of motion. Make equations for both the load and the trolley (in which the load is attached via rope). (100 p).

b) Form the **nonlinear** equations of motion that are needed for creating the simulation model of the system. Please use enough intermediate steps in your calculations. (300 p)

3. Components (600 p)

Select the following components from retailers. For miniature models, for example Sparkfun, Hobby Components, Hobbyking, etc. can be used. Try to select companies that provide datasheets for their products. Justify all the component selection decisions by explaining them briefly. You can use components found from existing inverted pendulum projects

Actuator (150 p)

a) Select an actuator that can move the trolley. Explain in detail how the actuator works. Draw a picture to support the explanation. Justify your selection. (100 p)

   Note that you need an actuator that is given position as input, not speed. (Alternatively, you may select an additional sensor that measures position.)

b) Name two advantages and disadvantages for using this type of actuator. These can be general issues or specific cases. (50 p)

Sensor (150 p)

a) Select a sensor that measures angle of the "rope". Explain in detail how the sensor works. Draw a picture to support the explanation. Justify your selection. (100 p)

b) Name two advantages and disadvantages for using this type of sensor. These can be general issues or specific cases. (50 p)

Power transmission, couplings and bearings (100 p)

Select at least three components related the power transmission, coupling and bearings of your machine. Justify your selection.

Electric components (200 p)

a) Select a controller. What is the ADC resolution of the controller? (50 p)

b) Select a power supply or a battery (50 p)

c) Draw an electric circuit sketch by hand or using a computer software such as KiCad. Include all the needed basic components (resistors, diodes, transistors, etc.) to your design to make it realizable and safe to use. **Attach this sketch to your report. (100 p)**

4. CAD modelling (500 p)

Make a 3D CAD model of your machine. The amount of points you receive from this task is defined by the level of detail of your design. You may use existing projects as reference, but use

of readymade models is prohibited. (Models of individual components can be used if available.) **Attach at least one picture per subsection and at least one picture of your final design to your report. Return your model in .stl or .stp (.step) format.**

Each subsection is graded the following:

- *0 points – section is not included in the model*
- *50 points – section is modelled*
- *100 point – section is modelled in detail*

1. Hook, trolley and rail frame modelled
2. Actuator and sensor modelled
3. Bearings and couplings/gears/belts modelled
4. Electronics modelled (e.g. controller and power supply, wires *NOT* needed)

5. Simulation model and control (900 p)

a) Make a Simulink model based on the nonlinear equations made in the *Numeric modeling* – section. Simulate a stepwise movement of the trolley without sway control. **Attach a figure with plots of trolley reference position, actual position, force, and rope angle to your report. (300 p)**

b) Make a (real-time) dynamic visualization that shows trolley position and rope angle of your system. The visualization can be for example similar to Fig 1 or even a 3D visualization. **The visualization must work in the returned MatLab files to get the points. (200 p) (**Pro tip: type "penddemo" to MatLab command window and run the simulation for inspiration.) **Attach video of the visualization into zip-folder you return. The visualization shall present performance with and without anti-sway.**

c) Introduce sway control to your system. Use any means necessary. Document the control and tuning method that you have used and phases how you implemented it. Compare the step responses with and without controller. **Attach a figure with plots of reference position of the trolley and rope angle plots with and without the sway control.** This task will be graded upon how well the control works and which method was used for tuning. **Return this model (.slx) and any related script file (.m) to A+ in a zip file. (total 400 p)**

1. Control performance: 0 to 200 points
2. Control and tuning methods: 0 to 200 points are given on the difficulty of the used method. Document how the method was used, no documentation means no points. The methods include for example PID with manual or IMC-based tuning.

   For reference: PID with manual tuning gives 50 p, Fuzzy Logic at least 100p, and Linear Quadratic Regulator (LQR) gives 200 p.

Control related videos for inspiration:
https://www.youtube.com/channel/UCm5mt-A4w61lknZ9lCsZtBw/videos

6. Feedback (100 p)

Please answer individually the following questions in the Feedback form in A+ (https://plus.cs.aalto.fi/mec-e5001/2023spring/projectwork/project_feedback):

- Did everyone participate to the project equally?
- How many hours in total did you spend (per person) for the project?
- How difficult was the project?
- Do you think that the topic of the project was interesting and useful?